The Germination of Vegetable and Field Crop Seeds as Affected by Two Soil Fumigants

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INTRODUCTION

The use of soil fumigants has become an established agricultural practice for the control of pathogenic organisms, especially soil nematodes. Considerable work has been done on the effect of these fumigants upon soil organisms, the increased amounts of available plant nutrients, subsequent plant growth, and yield. Extensive tests have indicated that the effectiveness of any fumigant has depended first upon the fumigant itself, second on the soil texture, third upon soil moisture, and fourth upon soil temperature. It has been established that some fumigants are more toxic than others. For all fumigants it has been generally believed that sufficient time should elapse after fumigation to allow adequate aeration of the soil to prevent toxic effects to the plants or germinating seeds. This interval of time would appear to depend on the concentration and type of fumigant used for any given soil type.

Some tests were made several years ago on tolerance of seeds to fumigants, but little definite information is available on this subject with soil fumigants. The use of ethylene oxide, carbon dioxide and carbon disulfide is well known for all kinds of stored food stuffs for protecting

against insects. There has been a rapid increase in use of fumigants for the destruction of insect pests infecting stored grains and other seeds. Since the fumigated grain could be used either for seed or food, it has been necessary to determine whether or not the germination capacity of seed would be affected and whether the grain thus treated would be injurious for food. One such test, made by Townsend (1899) with ether, indicated that a strong atmosphere of ether retards or prevents the germination of seeds and spores. Further work (1901) with hydrocyanic acid gas indicated that at higher concentrations the gas will kill the seeds or delay germination. He found that damp seeds were much more sensitive to the influence of gas than dry seeds. Hydrocyanic acid gas, however, is not recommended for regular soil fumigation and is little used in present day agricultural practices except under controlled conditions.

Soil fumigants are available both in liquid and solid forms, which generally vaporize when injected into soil, and relatively small quantities of chemicals are needed for effective control. Methyl bromide has been extensively tested by the Bureau of Entomology for the control of insects in nursery stock, fruits, vegetables, seeds, and soils. Numerous species of plants are not harmed by chemical concentrtions which kill insects. Atmospheric

fumigation of various seeds with methyl bromide was attempted by Gammon (1952). He reported that the germination of seeds will not be affected by ordinary dosages of methyl bromide, provided the moisture content of the seed is low. He also indicated that thorough aeration for two weeks should restore the germination to normal, if the germination percentage is lowered by the concentrations of gases tested. It is generally recognized in the commercial fumigation of wheat and other grains that the germination of seeds may be reduced if the moisture content of the seed at the time of treatment is relatively high. Also, it has been recognized that high temperatures and humidities at the time of fumigation will increase the toxicity of fumigant to insects, fungi, bacteria and seeds (53, 35, 52).

The conditions under which the toxicity of fumigants to various seeds have been reported do not exactly resemble the environment found when seeds are germinated in fumigated soil. In each test reported the seeds were exposed to the gas and later germinated in fumigant-free atmosphere. In the fumigated soil the seeds are germinating in the presence of varying levels of the volatile gases of the soil fumigant.

With this early work in mind, fumigation tests were conducted on several kinds of seeds with D-D and Dowfume W-40. The main purpose of this study was to find out whether these volatile soil fumigants are injurious to the germinating

ability of seeds, and if so, the type and extent of effect and under what conditions the injury occurs. Experiments were designed to germinate the seeds exposed to different concentrations of fumigants. Some of the remedial measures were also studied.

This study deals only with the cause and effect, while the nature of the action of the poison upon several parts of the seed still remains for further investigation.

REVIEW OF LITERATURE

Fumigation of stored products for protection against insects with hydrocyanic acid gas or carbon disulfide has been a well known practice for the last half century. The literature on this aspect of the subject is voluminous.

Soil fumigants, however, have only assumed great importance during recent years for the control of nematodes and killing of weed seeds in soil. Although the fumigants were mainly intended to destroy the pathogenic organisms in soil, they were found to affect also the beneficial organisms. The invigoration of beneficial organisms and availability of increased plant nutrients following fumigation is being investigated. Spectacular increases in yields, especially in vegetable crops, worth several million dollars have been reported in the last few years due to soil fumigation. However, the future development of soil fumigation is estimated to be of steady, rather than spectacular growth.

Germination Quality of Seed as Affected by Direct Fumigation

Townsend (58) was the earliest to report the effect of ether on the germination of seeds, even though a considerable amount of evidence concerning the usefulness of fumi-

gants against insects in stored grain was reported prior to his work. He stated that a weak atmosphere of ether hastened the time of germination of both seeds and spores, while a strong atmosphere retarded or prevented their germination. In later work (57) with hydrocyanic acid gas, he indicated that damp seeds are much more sensitive to the influence of gas than dry seeds. Dry seeds can be subjected for a short time to the influence of gas six times as strong as that ordinarily used in fumigation without any appreciable injury to the germinating ability of the seed. It was found that injury to damp seed would be materially lessened by washing the seeds as soon as they were removed from the fumigation chamber. He also noticed that seeds, in both dry and moist conditions, absorbed the hydrogen cyanide gas in different amounts from the surrounding atmosphere irrespective of the concentration. Zanotti (64) also stated that fumigation of Datura Stramonium L. and Hyoscyamus niger with hydrogen cyanide generated from 'Cyanogas A' exercised a stimulating or inhibiting action on the germination of seed, depending on the duration of the fumigation, concentration and mode of operation.

Barton's (4) work indicated that moist seeds of wheat and rye are more susceptible to hydrogen cyanide, ammonia, chlorine, hydrogen sulfide and sulfur dioxide than dry seeds, when exposed to concentrations of 250 and

1,000 PPM. for periods of 1, 4, 15, 60, and 960 minutes. Delay in germinating was the principal effect noted from the treatment. This delay was often accompanied by reduction in the germination percentage. In some instances all the seeds were killed. It was also recognized that sulfur dioxide, ammonia and chlorine were more toxic than hydrogen cyanide and hydrogen sulfide.

No effect was observed by Reifert et al. (40) on the germinating power of wheat, barley, rye, winter oats, and corn when exposed to vapors of ethyl acetate and carbon tetrachloride at a concentration of 40 pounds per 1,000 cubic feet for 24 hours in tightly closed bell jars.

Roark and Cotton (50) stated that the gases of aliphatic compounds have no effect on the germinating power of wheat. However, they pointed out that wheat seed, when fumigated, absorbs a certain quantity of the fumigant. The amount absorbed was greater with some fumigants than with others.

Young (63) tested six promising fumigants on 13 kinds of seeds in an attempt to select those most likely to be used in commercial fumigation. The fumigants tested were ethylene oxide, tertiary butyl chloride, isopropyl formate, methyl chloroacetate, ethylene dichloride and trichloroethylene. He kept the desired concentration of the fumigant directly on the seeds in stoppered Erlenmeyer

flasks for 24 hours at room temperature. His tests indicated that except for ethylene oxide and methylchloroacetate the remaining four fumigants could be safely used to fumigate wheat, oats, barley, rye, corn, buckwheat, sunflower, beans, lima beans, cowpeas, alfalfa, clover and timothy in concentrations up to twice the minimum lethal concentration required to kill the rice weevils without seriously impairing the germination of these seeds.

Richardson (49) observed no deleterious effect on corn or wheat with 9.1 percent or less moisture content, when fumigated with B-methyl-allyl-chloride at dosages up to 2.96 gallons per 1,000 bushels and length of exposures up to 168 hours. This dosage is about 13 times the maximum dosage required under the same conditions to kill 95 percent of the test insects. However, when the moisture content of the seeds was increased, he noticed a decreased percentage in germination even for the same concentration. Ethylene dichloride-carbon tetrachloride in 3:1 proportion caused no observable reduction in germination of corn and wheat.

McCallan et al. (33) established the fact that the fumigants vary in their toxicity to different organisms. He exposed various organisms to 1, 4, 16, 63, 250, and 1000 PPM. of gas for time periods of 1, 4, 15, 60, 240, and 960 minutes. The order of toxicity of gases at 1,000 PPM. was reported as follows:

Fungi and bacteria. . . . . SO_2, Cl_2 > NH_3 > H_2, HCN

Seeds and sclerotia . . . . . SO_2 > Cl_2, NH_3, HCN, H_2S

Green leaves.. . . . . Cl_2 > SO_2 > NH_3, HCN > H_2S

Green stems. . . . . No difference

Animals. . . . . HCN > H_2S > Cl_2 > SO_2 > NH_3

Types of seed also vary in their susceptibility to the gas under examination. Neifert et al. (41) working with various kinds of seeds and different gases, reported that on exposure to 2-3 percent phosgene at 27°C. and 40 percent relative humidity for 30 and 120 minutes did not affect the germination of alfalfa, carrot, clover, lettuce, onion, and radish, but injured muskmelon, millet and wheat. Arsine gas did not show any appreciable effect on seeds. Exposure of seeds to cyanogen chloride for more than six hours noticeably lowered the germination of wheat, oats, and barley and injuriously affected the seeds of Salvia hispanica, kaoling, velvet beans, milo, millet and grass. Shepard et al. (51) reported injurious effect to wheat seeds with sulfur dioxide and ethylene oxide.

In the past some evidence has been found that the common soil fumigants also affect the germination quality of seeds. Methyl bromide has been widely used in the last few years for fumigating fresh fruits, vegetables, stored grains and a variety of plants and shrubs for killing insect pests, as well as for killing soil organisms. In fumigating plants

with methyl bromide to control insect pests, the condition of the plant should be taken into consideration. English (15) applied methyl bromide to a wide variety of plants and found some plants to be more susceptible than others. He noticed that actively growing plants are more tolerant to methyl bromide injury than the less active ones.

Moore (37) was the first to use chloropicrin (tear gas) as an insect fumigant. He stated that chloropicrin is 168 times as toxic, molecule for molecule, as carbon disulfide. He fumigated various seeds and concluded that the seeds should be dry when fumigated. In one test he took navy beans directly from the field before they were thoroughly dry and fumigated them with chloropicrin at the rate of two pounds per 1,000 cubic feet for 24 hours. After thorough drying of the fumigated and non-fumigated beans, germination tests showed 95 percent in the case of check and 5 percent in the case of fumigated beans. Part of the check after drying, similarly fumigated, germinated 94 percent. Hoyt et al. (26) found no detrimental effect on germinating power of wheat, buckwheat, corn, oats, and sunflower when exposed to a concentration of 0.8 pounds of chloropicrin per 1,000 cubic feet for one week. On the contrary, he found somewhat improved germination of wheat and buckwheat. In later work (24) he fumigated various food products including grain, flour, foods and seeds packed in

different containers and in the open with ethylene dichloride-carbon tetrachloride mixture in 3:1 proportion for 24 hours at 75°F. He found no consistent effect on the germination percentage of wheat, oats, beans, peanuts, and clover. He also made comparative tests on the efficiency of several fumigants (calcyanide, chloropicrin, ethylene dichloride-carbon tetrachloride mixture, ethylene oxide, lethane 23, lethane 22 and carbon tetrachloride) against different species of insects, varieties of food products and seeds. His tests indicated that, with the exception of ethylene oxide, none of the above mentioned fumigants showed any deleterious effect on the germination quality of five varieties of seeds.

Evidence was also found that some seeds show more resistance than others to the same concentration of chloropicrin. Neifert et al. (41) reported that chloropicrin stimulated the growth of rice and timothy, but somewhat injured the seeds of alfalfa and radish when exposed to a concentration of 1.75 percent at 30°C. for 30, 60, and 120 minutes. A similar effect has been observed by Miege (36) where the seeds of wheat, rice, hemp and beet suffered a loss of 30 to 40 percent of their germinating power by a 24 hour exposure to a concentration of 1.6 pounds of chloropicrin per 1,000 cubic feet. The seeds of flax and several legumes lost none of their germinating power when exposed

to a concentration of over five pounds per 1,000 cubic feet. The data of Miege are contradicted by the evidence of Piedallu (47) who found no reduction in percentage germination of wheat when exposed to concentrations of from 0.6 to 2.0 pounds per 1,000 cubic feet. Piutti and Munge (48) stated that corn fumigated at the rate of two pounds of chloropicrin per 1,000 cubic feet for eight days lost one third of its germinating power.

Germination of Seeds as Affected by Fumigation of Soil

The review of literature shows evidence of toxicity of fumigants to some seeds more than others when planted in fumigated soil. Farrie (46) found no toxic effect on the germination of tomato seeds, when planted two weeks after D-D was applied to soil at the rate of 150 pounds per acre. Little phytocidal action by D-D mixture was noticed on germination of spinach seeds planted six days after soil treatment and none on those planted 14 days after treatment. There was some evidence of injury to peas planted 10, 12, 15, and 22 days after soil treatment with D-D. He did not observe any injury on peas planted 24 or 72 hours after treatment; however, injury was observed to beans planted 10 days after soil fumigation with D-D.

It is surprising to note lower yields of beans in all plots treated seven months before planting with chloro-

pierin, D-D, and Uramon than from the untreated plots as revealed in the data of Clayton and Ellis (8). They also found that low yields were more noticeable on plots treated seven months before planting with chloropicrin and higher rates of D-D than on those treated 10-14 months prior to planting.

Williamson (61) treated soils with formaldehyde in water (1-50) at the rate of 2 qts. per square foot, chloropicrin at the rate of ¼ ml. per ten inch square, methyl bromide at the rate of ½ pounds per 100 square feet, and di-bromo-butene at the rate of 8 grams per square foot. After a two-week aeration period he planted snapdragon seed in each plot. Germination of seeds was consistently lower in soil fumigated with methyl bromide and di-bromo-butene than in soils treated with formaldehyde and chloropicrin. Only 15 percent and 5 percent of snapdragon seeds germinated in plots treated with methyl bromide and di-bromo-butene respectively in comparison to 50 percent and 60 percent in plots treated with chloropicrin and formaldehyde respectively. Salvia seeds planted in the same soil nine months after fumigation with methyl bromide germinated very poorly and seedlings that did emerge grew slowly. Seeds from the same lot grew normally in the soil previously treated with chloropicrin or formaldehyde.

Magy et al. (27) treated seed beds with ethylene bromide at the rate of 20 gallons per acre dissolved in petroleum hydrocarbon fraction by injecting the fumigant for inches beneath the soil surface. The planting of vegetable seeds one hour after fumigation resulted in a germination of 90.5 percent for spinach and 100 percent for bush beans as against 100 percent for both in control plots.

Wilson and Christie (62) reported better germination of all crop seeds in soils treated with allyl bromide and ethylene dibromide mixture than in untreated soil. With methyl bromide no visible injury was noticed to eight varieties of seeds when planted seven days after fumigation.

Watson (60) reported the best results of stand, yield, and control of root rot when formaldehyde was applied to soil at the rate of 1.5 gallons per acre. However, 4.7 gallons per acre caused injury to peas, beans and lima beans.

Kincaid et al. (28) demonstrated that oat seeds sown before fumigation of the soil with D-D and Dowfume W-40 would not be damaged, provided there had been no rain for a few days after treatment. They also suggested the feasibility of sowing and fumigating the soil at the same time for saving labor and to take advantage of one rain for both fumigation and oat seed germination.

Taylor (56) treated soil having 5.2 percent moisture with methyl bromide in a fumigation box at a rate of 5.4 pounds per 1,000 cubic feet at 27°C. for 72 hours. When the soil was taken out of the fumigation box and planted to cucumber seed, no seed injury was observed. Newhall and Lear (44) also used methyl bromide at the rate of 11 ml. per cubic foot for the fumigation of soil in drums at temperatures of 48°F. and 60°F. for six days. After the soils were taken out, they were planted to spinach and beets. Only 2 percent of spinach and 16 percent of beets germinated in untreated soil in contrast to 42 percent of spinach and 88 percent of beets in soil treated at 48°F. while 45 percent of spinach and 88 percent of beets germinated in soil treated at 60°F. Compost piles were also treated with chloropicrin at the rate of 10 ml. per cubic foot and Dowfume G at the rate of 50 ml. per cubic foot. At the end of five days cucumber and spinach seeds were planted. They observed an increased percentage of germination of these seeds when compared to seeds in soil not fumigated. Thus, 87 percent of cucumbers and 64 percent of spinach in the case of chloropicrin, and 80 percent of cucumbers and 64 percent of spinach in the case of Dowfume G germinated in contrast to 54 percent of cucumbers and 16 percent of spinach in the untreated soil. The percentage germination of spinach, cucumber and sweetpea was increased by treating

compost piles with methyl bromide at rates of one half and one pound per cubic yard. Other soil was treated with Dowfume G at the rate of 60 ml. per injection on twelve inch centers at a depth of five inches. After 48 hours, the soil was planted to seeds of five vegetables, which gave a higher percentage germination than the same seeds planted in untreated soil. They also treated soils with chloropicrin, formaldehyde and Dowfume G for two days at 75°F. and found that cucumbers, spinach, tomatoes and beets gave a higher percentage of germination on the treated soils than in soils not treated. They explained this increased germination as due to the control of damping off disease.

Very little information is available on possible cumulative deleterious effects of successive treatments with fumigants. An experiment to study the effects of continuous, year after year applications of soil fumigants on the productivity of soil, especially influencing soil microorganisms, was initiated by Wilson and Christie (62). D-D and ethylene dibromide at rates of 23 and 46 gallons per acre were tried. English peas were used as an indicator crop. The peas germinated equally well in all plots, but about a week after germination, the peas on D-D plots showed evidence of stunting. A large number of plants were dead and others severely stunted by harvest time on D-D plots. No evidence of stunting was observed on plots treated with

ethylene dibromide. Nettles (42) found no harmful effects to Contender beans when the soil was fumigated continuously for five crops with D-D and Dowfume W-40.

Ellis et al. (14) treated soils with D-D, ethylene dibromide and chloropicrin for three successive years. No cumulative phytotoxic effects were found on the yields of tomatoes. However, there was an indication that D-D and chloropicrin treatments depressed the growth and yield of beans.

The time of application of fumigants also determines their toxic effect on the succeeding crop. Anderson et al. (2) from Connecticut, and Crittenden (10) from Delaware, reported lower yields of crops following spring treatment when compared to fall treatment. This they explained as due to volatile fumigants being lost more slowly from the cold soil in the early spring.

Promising results have been reported in the past on fumigants as an aid for weed control. Newhall and Lear (44) reported complete destruction of weeds in soil when treated with methyl bromide, chloropicrin or Dowfume G. In compost piles treated with chloropicrin and Dowfume G only 14 and 3 weeds germinated, respectively, in comparison to 1,287 weeds in the untreated piles. Similarly Anderson et al. (2), working with Dowfume MC-2, and Harvel (32) working with MC-2, reported considerable decrease in weeds

on treated plots. Marvel also stated that the broad-leaved weed populations were reduced more than 99 percent by all treatments. However, Godfrey and Young (20) stated that fumigants often failed to kill weed seeds and sclerotia of certain fungi in powdery, dry soil because seeds and sclerotia are resistant when very dry.

Effect of Soil Fumigation on Transplanted Seedlings

Several investigators have shown evidences of injury to transplanted seedlings in inadequately aerated fumigated soils. Parris (46) observed injury to tomato seedlings when transplanted 14 days after fumigation with D-D and trichloro-butanes injected six inches deep at the rate of 190 and 380 pounds per acre respectively. The injury was explained as due to the soil being a poorly drained silt loam of relatively low organic matter content, with pH 5.5. However, he observed no injury in the same soil when monochlorobutenes as fumigant was simultaneously injected at rates up to and including 1,000 pounds per acre.

Brooks (6) investigated the effect of two fumigants on transplanted seedlings. He set and watered Missionary strawberry plants 16 days after fumigating the soil with D-D and Dowfume W-40 each at the rate of 15 gallons per acre. Subsequent counts of dead plants showed a loss of 10 percent when treated with Dowfume W-40, 31

percent for D-D, and 14 percent in the untreated plots. He indicated that the increase of dead plants in the D-D treated plots was caused by the vapors of D-D remaining in the soil. Boehm (5) reported that in soil impregnated with illuminating gas the plants started growing, but their roots soon died. He reported that the roots are sensitive to gas injury. Crittenden (9) conducted experiments to determine whether fumigation treatments could be made at the time of seeding of a winter cover crop. He used three rates of ethylene dibromide (16, 26, and 36 gallons per acre) and D-D (13, 20, and 27 gallons per acre) in a field test. Applications were made 14 days after seeding of rye and rye-grass. The reduction in stand by ethylene dibromide for the three rates was, respectively, 12, 9, and 14 percent under that of the untreated areas. The reduction in stand for the three rates of D-D was, respectively, 38, 33, and 53 percent.

In tests to find a means to sterilize the roots without causing injury at the time of transplanting, Harrington and Pratt (22) tried both heat and fumigation treatments. They concluded that none of the heat treatments could be used for nematode control since the roots were injured. The fumigants (methyl bromide, ethylene dibromide and ethylene chlorobromide) also injured the roots of carrots and beets when the soil was fumigated to destroy

nematodes before planting.

On the other hand Gingrich et al. (18) observed no injury to cucumber plants set in the soil four to five days after treatment of the soil with methyl bromide.

Aeration as a Means to Reduce the Toxicity of Fumigants

Limited studies indicate that the time limit before planting in fumigated soil varies with the dosage, type of fumigant, temperature of soil, weather conditions and also with the particular plant. Nettles (43) recommended that two to three weeks time should elapse before planting vegetable seeds when D-D and ethylene dibromide are applied to soil, but with methyl bromide the area can be planted within 48 hours. Munnecke et al. (39) working with methyl bromide, observed no toxicity either to seeds or to transplants if the soil was aerated for 24 hours before using. In finding the aeration period necessary before planting, they planted China-aster, bean, pea and pepper seeds in flats after a three-hour aeration period. Peppers germinated poorly and were stunted, but the other seeds produced plants comparable to those grown in steamed soil.

Besides the evidences quoted above, there are few instances reported in the literature indicating an increased percentage of germination of fumigated seeds after aeration. Moore (37) stated that large doses of chloropicrin do injure

the germination, if germination is attempted before the grain has had a very thorough airing. Rye with a germination of 99 percent was fumigated at the rate of two pounds per 1,000 cubic feet for 25 hours. A germination test eight hours after seed was removed from the fumigation box gave 81 percent, 24 hours 81 percent, 48 hours 95 percent, and 72 hours 98 percent.

Gunson (16) while testing resistance of various seeds to methyl bromide indicated that if germination is retarded by fumigation, thorough aeration for two weeks would restore the germination to normal; but if the final germination has been lowered, it is impossible to increase the percentage germination.

Effect of Humidity Upon the Toxicity of Fumigants

The role of humidity in the toxicity of fumigants has not been thoroughly understood. Atmospheric humidity, the stage of development and the physiological condition of the insect affect importantly the efficacy of a fumigant, as pointed out by Shepard and Lindgren (52).

Dobie et al. (12), in fumigating sweet potato storage houses with chloropicrin, recommended that a relative humidity approaching saturation was necessary for effective control of fungi. Nugent and Cook (45) in fumigating storage houses with chloropicrin observed that

dosages as low as one ounce per 1,000 cubic feet were effective against Rhizopus nigricans and Ceratostomella fimbriata in a moist atmosphere, but that even much higher concentration was ineffective when the atmosphere was dry. Mercandier (35), working with bacteria, and Stark (53), working with seeds and fungus spores, stated that high humidity during fumigation markedly increased the toxicity of chloropicrin. Stark reported, furthermore, that humidity in the treating chamber exerts greater influence on the susceptibility of seeds than does the moisture content of the seed itself. This was explained as due to the effect of humidity on the increased moisture content of the seed coat and thus on its permeability to the gas. He presumed that gases probably would enter the seed by going into solution in the water in the seed coat and diffusing through water to the embryo. Evidence to this effect was also shown by Heerdt (23), who concluded that foods with high moisture content absorb notable quantities of hydrocyanic acid on fumigation. Uncovered fluids and moist foods, especially oils and fats, when exposed to hydrocyanic acid gas absorb large amounts of it.

Evidence indicating no relation between relative humidity and toxicity of fumigant was also found in the literature. Chapman and Johnson (7) found no relation between humidity and toxicity of chloropicrin to adult

granary weevils (Sitophilus granaria, L.). Lindgren and Shepard (30) stated that variation in relative humidity has no effect on the toxicity of ethylene dioxide, carbon disulfide and chloropicrin to adult insects. However, the eggs of Tribolium confusum Duval were affected by these gases in the presence of high humidity.

There has been considerable evidence to suggest that seeds with high moisture content are more susceptible to fumigation injury than are those with low moisture content. Townsend (57) was the earliest to report that moist seeds were more susceptible to hydrocyanic acid gas than dry seeds. Davey and Leach (11) stated that chloropicrin had no effect on dry sclerotia of Sclerotium rolfsii, but if the sclerotia were soaked in water and exposed to gas, complete kill was obtained. Nugent and Cook (45), while trying to control black rot of kale seeds with chloropicrin, reported that as the moisture content of seeds was increased, the injury to seeds became greater and control of Xanthomonas campestris was improved. Gammon (16), working with methyl bromide, stated that caution should be taken in fumigating seeds with high moisture content at recommended doses or at schedules higher than at one pound per 1,000 cubic feet for 24 hours.

Effect of Temperature Upon the Toxicity of Fumigants

In general, it has been agreed that fumigants were most effective at higher temperatures. Considerable work has been done on this aspect of the subject, especially in controlling insects and diseases. Ginsburg (19), working with rice weevil and confused flour beetle, reported increased toxicity of fumigants with increase in temperature.

Nugent and Cook (45), while treating infested kale seed, and Mercandier (35), working with bacteria, demonstrated that raising the temperature markedly increased the toxicity of chloropicrin to fungi and bacteria. The fact that temperatures affect the toxicity of all fumigants, but some more than the others, was reported by several investigators. McClellan et al. (34) reported that D-D was not effective against Fusarium oxysporum, F. Callistephi or Sclerotium rolfsii, but was effective against Heterodera marioni, causing complete kill at 82°F. after one day, and at 62° and 72° F. after three days. Dowfume W-15 was not effective against Fusarium oxysporum or F. Callistephi, but was effective against Sclerotium rolfsii at 72°, 82°, and 98°F. after one day, and was effective at lower temperatures after three days. Godfrey and Young (20) obtained best results in the killing of organisms in soil with chloropicrin when the temperature of the soil at a

depth of six inches was warmer than 65°F. Turner and Dieter (59), in reviewing the factors that influence the effectiveness of ethylene dibromide as a soil fumigant, indicated that best results could be obtained if the soil temperature at the 6-8 inch depth is in the sodium range. If the soil temperature was too high, the fumigant might diffuse out too rapidly and escape from the soil before lethal concentrations were present for sufficient time to control. This was especially true if soil moisture was low. Low soil temperature, on the other hand, retarded the diffusion of the fumigant so that toxic concentrations might not be obtained throughout the soil mass. Low soil temperatures also interfered with the proper aeration of the fumigant from the soil, so that toxic residues might remain. This situation is accentuated in wet soils. Dobie et al. (12) reported that a temperature above 70°F. was essential for effective control of fungi in sweet-potato storage houses with chloropicrin.

Little work has been reported on the effect of temperature upon the toxicity of fumigants to seeds. Stark (53), working with chloropicrin, found that raising the temperature markedly increased the toxicity of chloropicrin to seeds. He further stated that raising the temperature over a given range does not exert the same influence on all kinds of seeds. Increasing the temperature from

33° to 72°F. had only a slight influence on the toxicity of chloropicrin to turnip, spinach and carrot seeds, whereas the same change in temperature markedly increased the toxicity of the same dosage of chloropicrin to wheat and beet seeds.

Miscellaneous

There are only a few indications made in the literature about the toxic effect of fumigants on enzymatic activity. However, it was evident that certain gases are absorbed in sufficient amounts by moist seeds to inhibit the germination of some seeds more than others. Moore (38) mentioned that hydrocyanic acid is soluble in water and even minute quantities are sufficient to inhibit the action of oxidizing enzymes. Chloropicrin likewise was thought possibly to be an enzyme poison. On the other hand, Townsend (58) reported that ether did not affect the transformation of starch by diastase. In fact, his results showed that a solution of starch containing 0.1 ml. of ether was transformed much more readily than those not having the ether.

MATERIALS AND METHODS

General

In this study fumigation experiments were conducted in sealed containers, storage chambers, greenhouse benches and field plots. The experiments in sealed containers were made using two gallon jars. These soilless containers were used as fumigation chambers to which the desired concentrations of soil fumigants were added. The fumigants were placed on pieces of filter paper and dropped into the jars which were immediately sealed with a screw top. During the period the tests were conducted the jars were kept in the laboratory under fairly uniform conditions. Other experiments in sealed containers were made using laboratory desiccators.

Tests made in storage chambers and in greenhouse benches employed soil as the medium to which the fumigants were added, and, therefore, more closely resembled the conditions found in the field plots.

The details of procedures used will be discussed under each of the several experiments.

The concentration of fumigants used varied from experiment to experiment. This was due to the different

conditions provided in the different tests conducted. Also in preliminary studies made with lower concentrations than those reported in the respective tables, the concentrations did not show appreciable influence on the seeds. The concentrations used in the different fumigation chambers were converted to milliliters per cubic foot.

The percentage figures were transformed to corresponding angles for statistical analysis according to the table given by Snedecor, since the means for Poisson distribution cannot be compared like those from the binomial distribution. In the presentation of results, the means were changed back to appropriate percentage means. The significant differences were tested by multiple range tests (13) and least significant differences. The data presented represents the average of four replications.

Seeds of varieties of plants whose germination was tested in one or more experiments are as follows:

Plant	Variety
Beans	Contender
Beets	Early Blood-Red Market
Broccoli	Green Sprouting
Cabbage	Charleston Wakefield
Carrot	Imperator
Cauliflower	Super Snow Ball
Celery	Green Florida Pascal
Clover	Alyce Clover
Cucumber	Marketer
Egg plant	Florida Market
Lettuce	Great Lakes
Mustard	Florida Broad Leaved
Oats	Victory
Okra	Perkin's Early Mammoth
Onion	Crystal Wax Bermuda

Plant	Variety
Rutabaga	American Improved
Rye	Abruzzi
Spinach	Virginia Savoy
Sweet corn	Golden Hybrid
Tomato	Grothen Globe
Turnips	Shogoin
Watermelon	Dixie Queen

Throughout these tests two fumigants were used.

1. D-D: This is a mixture containing approximately 2/3 dichloropropene and 1/3 dichloropropane and a small portion of trichlorides with high boiling point. It is a brownish liquid, slightly oily, about 1/5 heavier than water, completely volatile and non-inflammable. It has a pungent, sweetish, and nauseating odor, often causing inflammation of skin after a few minutes of contact. In the presence of moisture it is corrosive to metals.

2. Dowfume W-40: This is a liquid mixture containing 41 percent by weight of the active ingredient, ethylene dibromide. Materials containing this compound are sold commercially under various other trade names. Dowfume W-40 is insoluble in water, non-inflammable, non-corrosive, and volatile.

In this study, germination was defined as the emergence and development from the seed embryo of those essential structures which for the kind of seed in question are indicative of the ability to produce a normal plant under the conditions tested. Germination is expressed as the percen-

tage of the kind under consideration which produces normal seedlings. The differentiation of normal and abnormal seedlings was made according to the instructions given in Agricultural Handbook No. 30, (1952), U.S.D.A. Testing Agricultural and Vegetable seeds. The work reported here was conducted in cooperation with the Florida Agricultural Experiment Station.

Experiment No. 1. The Germination of Seeds as Affected by D-D, Dowfume W-40, Length of Exposure and Fumigated Water

1-A. Germination of Various Seeds in the Presence of Vapors of Soil Fumigants

The object of this experiment was to germinate the seeds in an atmosphere of fumigant vapors, a condition which might be similar to that occurring with seeds germinating in the fumigated soil. The equipment used is illustrated in Plate I. Approximately 50 ml. of water was placed in a petri dish at the bottom of the fumigation chamber and a stand 2 1/2 to 3 inches high was placed in the center of the dish. The seeds to be tested were evenly spread on moist filter paper in a one-end petri dish. In the dish with seeds, three or four strips of filter paper 4-5 inches long and 1/2 to 3/4 inch wide were placed with one end being pressed under the moist filter paper. These strips were placed at equidistant from one another

PLATE I

Equipment Used to Determine the Effect of Soil Fumigants on the Germination of Cucumber Seeds. Left to right, Dowfume W-40, D-D, and Check.

around the edge of the dish. The other end of each filter paper strip was immersed into the water of the bottom dish when the petri dish containing the seeds was placed on the top of the stand. The strips of filter paper absorbed the water from the bottom dish and supplied moisture to the germinating seeds. Since the seeds were left in the fumigation chamber from 5-7 days, depending on the type of seed, without being disturbed until completing germination, the moistening of filter paper was essential. The seeds were then treated at the rate of 0.03 ml. of each fumigant per cubic foot. The concentration of fumigant used was low because the preliminary tests made with concentrations 0.06, 0.09, and 0.12 ml. per cubic foot resulted in a complete kill of the seeds. Control tests were made precisely in the same manner except the seeds were not exposed to the fumigants. The percentage of seeds germinated was recorded when germination was completed.

Experiment No. 1-B. Effect of Length of Exposure of Seeds to D-D and Dowfume W-40 on Their Germination

To determine whether the life of the seeds in the presence of vapors of fumigants was destroyed or whether the germinating power was simply suspended, the following experiment was undertaken. Equal numbers of seeds were spread evenly on moist filter papers in two petri dishes

for germination in an atmosphere of gas at the same concentration as described in the previous experiment. After 4 or 5 days, depending on the time required for germination of the kind of seed under examination, one petri dish was removed from the fumigation chamber and placed outside in ordinary atmosphere. The other petri dish was left in the fumigation chamber. The seeds taken out of each chamber were moistened by adding drops of fresh water to the filter paper. Control experiments were made in exactly the same manner except the seeds were not exposed to fumigants. At the end of the experiment, when the seeds had germinated, they were counted in both petri dishes and recorded.

Experiment No. 1-C. Effect of Water Exposed to Soil Fumigants on the Germination of Seeds

In order to find out whether the water kept in the fumigation chamber had any effect on the germination capacity of the seeds, the following test was made. The water from the petri dish located at the bottom of the chamber in the previously described experiments was taken out after 5-7 days. Seeds of cucumber and mustard were germinated on filter papers moistened with this water from the fumigation chambers. The percent of seeds germinated was recorded when germination was completed.

Experiment No. 2. Effect of Absorption of Soil Fumigants by Water on the Subsequent Germination of Cucumber Seeds

This experiment was a more detailed study of the effect of gas absorption by water on the subsequent germination of seeds when higher rates of fumigants were used.

Two quantities of water, 50 and 100 ml., each were exposed to the vapors in fumigation chambers at concentrations of 0.16, 0.33, and 0.66 ml. of each fumigant per cubic foot for periods of 12, 24, and 48 hours. At the end of the exposure period water was taken out of the fumigation chamber and the pH measured immediately with a pH meter equipped with a glass electrode. Seeds of cucumber were tested for germination on filter paper moistened with this water. In addition, two other equal portions of water which were exposed to the fumigants were aerated for a duration of one and two weeks. The pH was then measured at the end of these two scheduled periods of aeration. Cucumber seeds were again tested for germination using the two respective samples of aerated water to moisten the seeds as needed. Both normal and abnormal seedlings were counted after germination and recorded. Control tests were made using the same procedure except that the water used for moistening the cucumber seeds was not exposed to either of the two fumigants.

Experiment No. 3. Germination of Various Seeds as Affected by the pH of Water

A test was made to determine whether the decreased percentage germination of cucumber seeds found when moistened with water exposed to the higher concentrations of fumigant vapors was due to the change in pH of water. Germination tests were made with six varieties of seeds, using water to moisten the filter paper for germination whose pH was adjusted using hydrochloric acid. This water was adjusted to a pH of 3.1, which was approximately equal to that produced by the higher doses of each fumigant. Control experiments were made using tap water whose pH was not adjusted. The percentage of seeds germinated was recorded after germination was completed.

Experiment No. 4. Effect of Soil Fumigants on Dry Seeds

Air-dried cucumber seeds stored at room temperature were placed on watch glasses and exposed to each of the two fumigants at concentrations varying from 1.98 to 6.60 ml. per cubic foot for 3, 5, and 7 days in sealed two-gallon jars. Preliminary tests made at lower concentrations of 0.99 and 1.32 ml. of fumigant per cubic foot did not show any appreciable effect on the germination of seeds. A thin layer of seeds was placed in each dish so that the vapors

of the fumigant came directly into contact with each seed. At the end of the period of treatment the seeds were taken out of the fumigation chamber. Half of the seeds were immediately tested for germination on moist filter paper in room atmosphere and the remaining half were aerated for ten days and then tested for germination. Control tests were made in precisely the same manner and kept under exactly the same conditions as above except that the seeds were not subjected to the influence of the fumigant. Germination records were maintained for the seeds in each treatment.

Experiment No. 5. Effect of Soil Fumigants on Damp Seeds

This experiment was undertaken to determine what effect each of the fumigant vapors would have upon seeds that had been soaked in water for different lengths of time. Cucumber and mustard seeds were soaked in water for 12 and 24 hours, the water was drained off, and the seeds were spread in a thin layer on watch glasses. The seeds were then exposed to each of the fumigants at strengths of 0.66, 1.32, and 1.98 ml. per cubic foot for durations of 2, 4, and 6 hours. Half of the seeds exposed to D-D were rinsed in water immediately after fumigation and then tested for germination. The remaining seeds were tested for germination on moist filter paper without rinsing. Control experiments were conducted under the same conditions, except

the seeds were not exposed to the vapors of fumigants. The results were recorded after the germination was completed.

Experiment No. 6. The Influence of Relative Humidity on the Toxicity of Soil Fumigants

6-A. Effect of Humidity Upon the Toxicity of Soil Fumigants to Seeds

Before determining the effect of humidity on the toxicity of fumigants, various seeds were held in a desiccator over calcium hydroxide for five days before treatment to standardize the moisture content. The seeds were then exposed to the vapors of fumigants under controlled conditions of humidity. This was accomplished by holding four lots of 100 seeds of each species in a desiccator in which a relative humidity of 20 percent was maintained by using a saturated solution of potassium acetate. Similarly four lots of 100 seeds of each species were held in another desiccator having 100 percent relative humidity maintained by pure water. The fumigants were applied at the rate of 13.6 ml. per cubic foot to each desiccator and the seeds were treated for 48 hours. The preliminary tests conducted at the concentrations of 6.6 and 9.9 ml. of fumigant per cubic foot did not show any appreciable influence on seeds. Temperature during the treatment varied from 70° to 75°F. The seeds were removed after the exposure period and aerated for five days and then tested for germination.

The effect of other levels of humidity on the toxicity of fumigants was also determined. Seeds were tested in desiccators in which relative humidities were held at 52, 81, and 93 percent. The humidities were maintained by using saturated aqueous solutions of calcium nitrate, ammonium sulfate, and ammonium dihydrogen phosphate, respectively. Temperatures during treatment varied from 70° to 75°F. The fumigants were added at the rate of 13.6 ml. per cubic foot for each desiccator and the seeds were exposed again for 48 hours. After treatment, the seeds were exposed to air for five days before germination tests were started. The germination tests were then conducted and the results tabulated.

Experiment No. 6-A. The Effect of High Moisture Content of Exposed Seed as Compared to High Humidity in the Atmosphere on the Toxicity of D-D

To determine whether the increased toxicity of fumigant in the presence of humidity is a result of the seeds absorbing moisture in a humid atmosphere and hence being more susceptible to the gas, or is a direct influence of the humidity of the atmosphere on the effectiveness of fumigants, the following experiment was conducted. Four varieties of seeds were held over calcium hydroxide for five days before treatment to standardize the moisture content of the seeds. Eight lots of 100 seeds of each

species were held in a desiccator in which 20 percent relative humidity was maintained by saturated aqueous solution of potassium acetate. An equal number was held in another desiccator at 100 percent relative humidity. After 24 hours, half of the seeds were removed from the low humidity and placed in the high humidity chamber and half of the seeds were removed from the high humidity and placed in the low humidity chamber. All the seeds were then treated with the fumigant at the rate of 9.9 ml. per cubic foot for 24 hours. Temperature during the treatment varied from 72° to 76°F. After treatment the seeds were aerated for five days and then tested for germination. Records were made on the number of seeds germinating in each treatment.

Experiment No. 7. Effect of Temperature Upon the Toxicity of Soil Fumigants to Seeds

To find the effect of temperature upon the toxicity of fumigants to seeds, four lots of 100 seeds of each species were treated with each fumigant at the rate of 13.6 ml. per cubic foot in desiccators stored at 55, 65, 75, 85, 95 and 100°F. The seeds exposed to fumigants at concentrations of 6.6 and 9.9 ml. per cubic foot were not appreciably affected. The lower temperatures of 55° and 65°F. were maintained in cold storage rooms and the higher temperatures were maintained by thermostatic control in a heated insulated wooden cabinet. In all these tests a relative humidity of 81 percent was maintained in the desiccators by a saturated

aqueous solution of ammonium sulfate. After treatment the seeds were aerated for five days and then germinated. Counts of the number of seeds germinating were made in each treatment.

Experiment No. 8. Effect of Soil Fumigants on the Digestion of Starch by Diastase

This experiment was conducted to find out whether the inactivity of the vital action of seeds found in the atmosphere of low concentration of fumigant was due to the inability of the enzyme to transform the stored carbohydrates into compounds that may be used by the plants, or whether it was due to an influence produced upon the protoplasm. A 4 percent starch solution was made to which acetate buffer (pH 4.5) was added at the rate of 2 ml. for each 100 ml. of final volume of starch solution. Twenty milliliters of starch solution was placed in petri dishes to which one milliliter of 0.5 percent taka-diastase solution was added and exposed to each fumigant at the rate of 1.98 ml. per cubic foot. Samples of starch solution were taken at intervals and tested for the presence of starch with potassium tri-iodide solution, which gives a blue color with starch. The time taken for the disappearance of starch in those treatments exposed to the fumigant vapors was recorded as compared to the time in treatment receiving no exposure.

Experiment No. 9. Effect of Time of Application of Soil Fumigants on Transplanted Tomato Seedlings

This experiment was conducted in the field during the month of April, 1954. The land was thoroughly plowed and levelled. Rows for treatment were 50 feet long and 3 feet apart. Three application dates were tested, each made at 5-day intervals. The application of the fumigant was done by injecting the material into holes made at intervals of one foot at a distance of six inches on either side of the row. The holes were made in such a manner that those on opposite sides of the row were staggered alternately. The holes were 4-5 inches deep, and the fumigants were applied at the bottom of the holes by pouring 3-4 ml. of the material down a long-stemmed funnel. The hole was immediately closed and the soil firmed. Each treatment was replicated four times. The first application of fumigant was ten days before transplanting, the second five days before transplanting, and the third on the same day as transplanting, so that the resistance and growth performance of seedlings could be compared. One hundred tomato seedlings, one month old, were transplanted to each row. After 15-20 days the seedlings which survived were counted.

Experiment No. 10. Effect of Time of Application of Soil Fumigants on Field Germination of Seeds

The method and time of application of the fumigants were those described in Experiment No. 9, except that 100 bean seeds were planted in each treatment instead of tomato seedlings. The soil was dry for a depth of 1 1/2 to 2 inches at the time of planting and water was applied as irrigation to each of the two days after planting. After the second day water was applied only every 3-4 days until the seeds germinated. The number of normal seedlings was counted and recorded for each treatment.

Experiment No. 11. Effect of Soil Fumigants at Different Soil Temperatures on the Germination of Seeds

To determine the effect of temperature, metal pans 24" x 15" x 5" were prepared with electric heating coils located on the bottom. The pans were filled with soil to a depth of four inches and the soil temperatures were adjusted to 55, 68, 75, 86, and 92°F. by means of thermostat controls. The lower temperatures, 55 and 68°F. were maintained by placing the pans of soil in cold storage rooms and the pans tested at the higher temperatures were placed in the laboratory. The soil temperatures in the pans in the laboratory were maintained fairly constant by means of thermostat control since the room temperature was lower than the desired temperatures. Bean and watermelon were used as the

test crops and were planted one hour before fumigation. The soil was fumigated by injecting 5 ml. of fumigant for each pan into six holes at a depth of 1 1/2 to 2 inches. Each hole was immediately closed and the surface of the soil was moistened with water to a depth of 1/2 inch for a gas seal. The soil dried quickly due to high temperatures and shallowness of soil, and water was sprinkled on the soil surface as found necessary. Control tests were also run in the same manner except the soil in these pans was not fumigated. After 10-15 days the germinated seedlings were counted and recorded.

Experiment No. 12. Effect of Quantity and Time of Application of Water Seal to the Soil Surface on the Toxicity of Soil Fumigants to the Germination Quality of Sweet Corn

This experiment was conducted in the greenhouse where the temperatures ranged from 75°-90°F. Soils of two different textures (sandy and sandy loam) were placed in glazed crocks, eight inches in diameter and twelve inches deep. Twenty crocks were filled with each soil and placed in the greenhouse, and 100 seeds of sweet corn were planted 1 to 1 1/2 inches deep in each crock. Four of the crocks filled with each soil were not treated with fumigants, but the remaining soil-filled crocks were fumigated four hours after planting. This was accomplished by placing one milliliter of fumigant in the center of each crock at a depth

of 4-5 inches. The concentration of fumigant used was low as compared to some of the other experiments because in the preliminary tests conducted with concentrations of 1.5 and 2.0 ml. per crock the germination of sweet corn was completely inhibited. The crocks receiving no fumigation treatment were sprinkled with 100-150 ml. of water to wet the soil surface. Four of the crocks with each soil did not receive any water, four were surface watered with 100 ml. of water immediately after fumigation, four received 200 ml. of water immediately after fumigation, and the remaining four received 100 ml. of water two hours after the fumigant was injected. No further water was applied until two days after treatment, when watering on the surface was started in all crocks and continued throughout the test as found necessary. The seedlings in each crock were counted after 10-15 days and the results recorded.

RESULTS AND DISCUSSION

Experiment No. 1. The Germination of Seeds as Affected by Soil Fumigants, Length of Exposure and Fumigated Water

1-A. Germination of Various Seeds in the Presence of Vapors of Soil Fumigants

The germination percentage of various crop seeds as affected by the two soil fumigants, D-D and Dowfume W-40, is presented in Table 1. It appears from the data presented that the percentage germination of most seeds tested was affected by the exposure to either D-D or Dowfume W-40. The vapors of the two fumigants resulted in a significant reduction in the germination of most of the seeds when compared to the germination found in fumigant-free atmosphere. The germination of cucumber and cauliflower seeds, however, was not appreciably affected by the exposure to Dowfume W-40. In comparing D-D with Dowfume W-40, the percentage germination of twelve of the twenty crop seeds tested was significantly reduced by exposure to the vapors of D-D below that of those exposed to Dowfume W-40. No significant differences were found in the germination percentages for the seeds of the other eight crops.

TABLE 1

GERMINATION OF VARIOUS SEEDS IN THE PRESENCE OF VAPORS OF SOIL FUMIGANTS

Crop Seeds	Percentage Germination			Shortest Significant Ranges (5% level)	
	Check	Dowfume W-40	D-D	2 Means	3 Means
Beets	55.0	26.3	25.0	11.9	12.3
Broccoli	79.5	63.0	52.0	4.4	4.5
Cabbage	80.5	70.0	16.5	3.6	3.7
Carrots	72.3	43.0	0.0	6.0	6.2
Cauliflower	91.0	89.0	2.0	5.8	6.1
Celery	73.0	0.0	0.0	1.6	1.6
Clover	71.0	59.0	0.0	2.8	2.9
Corn	94.5	16.5	25.5	5.7	5.9
Cucumber	92.0	87.0	16.3	6.5	6.7
Egg plant	75.0	0.0	0.0	2.2	2.3
Lettuce	92.5	0.0	0.0	3.0	3.2
Mustard	66.0	14.0	5.0	6.6	6.8
Oats	87.0	0.0	0.0	6.6	6.8
Okra	75.0	82.5	66.5	3.9	4.1
Onion	74.0	16.0	18.5	5.5	5.7
Rye	86.0	0.0	0.0	2.9	3.0
Rutabaga	91.0	50.0	38.0	8.2	8.5

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

TABLE 1 (Continued)

Crop Seeds	Percentage Germination			Shortest significant Ranges (5% level)	
	Check	Dowfume W-40	D-D	2 Means	3 Means
Spinach	46.8	4.0	10.0	6.3	6.5
Tomato	78.8	11.3	5.0	5.2	5.4
Turnips	67.4	16.0	2.0	6.0	6.2

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

It is evident that the germination capacity of some crop seeds is more severely affected than that of others. For example, the seeds of broccoli and okra, although the germination was significantly reduced by both fumigants, had comparatively high percentages of germination. On the other hand, seeds of beet, corn, mustard, onion, spinach, tomato, and turnip had a very low germination when exposed to the same concentration of fumigants. Seeds of rye, oats, egg plant, celery and lettuce were apparently killed, as no germination of these seeds resulted. The variation in the relative susceptibility of different crop seeds is not well understood. From the data presented there was no indication that the seeds belonging to one family or group are more or less susceptible than those of another.

Experiment No. 1-B. Effect of Length of Exposure of Seeds to D-D and Dowfume W-40 on Their Germination

From the results of the previous experiment it was evident that seeds of some crops were able to germinate and some were unable to germinate in the presence of the soil fumigants using the concentration tested. It was considered essential to determine whether the seeds were killed or whether the germination was simply retarded in the presence of fumigants. Table 2 shows the percentage germination of seeds exposed continuously to the vapors of each fumigant and of those seeds taken out of the fumigation chamber after only 4-5 days exposure. The results show that the seeds of several crops taken out of the presence of fumigants after 4-5 days and germinated in room atmosphere had a significantly higher percentage germination than those which remained in the presence of fumigants throughout the experiment. However, the seeds of turnip, oats, rye, celery, cauliflower, and onion when exposed to D-D for 4-5 days and of lettuce, oats, celery, and onion when exposed to Dowfume W-40 for 4-5 days, gave a very poor germination even after having been taken out of the presence of fumigants. Lettuce seed exposed to D-D for 4-5 days germinated 71.3 percent in the room atmosphere, but surprisingly the seeds were killed after exposure to Dowfume W-40 for the same length of time. Normal germination in

TABLE 2

PERCENTAGE GERMINATION OF SEEDS AS AFFECTED BY LENGTH OF EXPOSURE TO D-D AND DOWFUME W-40

Crop Seeds	Continuous Exposure	Exposed 4-5 Days	Non-exposed	Shortest Significant Ranges (5% level) 2 Means	3 Means
		D-D			
Lettuce	0.0	71.3	92.5	5.1	5.3
Turnip	2.5	34.5	67.0	5.2	5.3
Oats	0.0	7.0	87.0	4.4	4.5
Rye	0.0	5.0	83.0	3.1	3.2
Rutabaga	35.0	62.5	89.0	2.2	2.3
Broccoli	52.0	73.3	78.5	2.0	2.1
Celery	0.0	0.0	71.3		
Cauliflower	5.5	17.3	89.0	5.6	5.8
Onion	18.5	30.0	73.0	4.1	4.2
		Dowfume W-40			
Lettuce	0.0	0.0	92.5		
Turnip	15.3	45.8	67.0	4.2	4.3
Oats	0.0	10.5	87.0	3.3	3.4
Rye	0.0	2.5	83.0	3.0	3.2
Rutabaga	50.0	80.5	89.0	7.0	7.2
Broccoli	63.0	83.8	78.5	2.4	2.4
Celery	3.0	23.5	71.3	3.9	4.4
Cauliflower	91.0	93.8	89.0	3.2	3.3
Onion	16.8	28.5	73.0	4.7	4.8

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

not restored with all seeds tested even after being removed from the presence of fumigants. The higher germination percentage of some seeds observed in room atmosphere after an exposure for 4-5 days to fumigants indicates that germination was retarded for a short period of time in the presence of the soil fumigants. It is also evident from the data

presented that whether seed germination was merely retarded or death of the seeds occurred upon exposure to the vapors of fumigants appears to depend on the type of seed involved. With some seeds germination was severely retarded and many of these seeds were actually killed, as evidenced by the low germination percentage of oats and rye. With other seeds only a relatively small number of seeds were actually killed, with retardation of germination still being evidenced. It is interesting to note that some seeds of all crops, except cauliflower and broccoli had been killed by exposure to Dowfume W-40.

Experiment No. 1-C. Effect of Water Exposed to Soil Fumigants on the Germination of Seeds

This experiment was undertaken with the assumption that the vapors of fumigants might dissolve in water and would affect germination of seeds as reported with hydrocyanic acid gas by several investigators (52, 20, 3). The data in Table 3 show the effect of using fumigant vapors to treat the seeds, as compared to watering the seeds with water which had been exposed to the soil fumigants, on the germination percentage of cucumber and mustard seeds. The results indicate that significant differences in the percentage germination between the two treatments occurred. The use of fumigants as a vapor at the lower concentrations was more detrimental to the germination of

TABLE 3

GERMINATION OF SEEDS EXPOSED TO SOIL FUMIGANT VAPORS AS COMPARED TO THOSE TREATED WITH WATER EXPOSED TO SOIL FUMIGANTS

Crop Seeds	Concentration (ml./c.ft.)	Percentage Germination		Shortest Significant Ranges (5% level) 2 Means
		Fumigant	Exposed Water	
		D-D		
Cucumber	0.16	0.0	96.5	10.9
	0.33	0.0	93.5	8.2
	0.66	0.0	0.0	
Mustard	0.16	0.0	72.0	3.6
	0.33	0.0	6.0	3.6
	0.66	0.0	0.0	
		Dowfume W-40		
Cucumber	0.16	64.3	96.5	6.6
	0.33	50.3	94.0	13.2
	0.66	0.0	92.5	3.2
Mustard	0.16	7.8	73.3	3.2
	0.33	4.3	72.0	34.8
	0.66	0.8	63.5	2.9

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

seeds than when water which had been exposed to the same concentrations was applied to the seeds. At the higher concentrations of the fumigants tested, the exposed water absorbed a sufficient amount of the vapors of fumigant to cause it to be equally toxic as the fumigant vapors. The

water which was exposed to D-D was much more toxic than the water exposed to Dowfume W-40. At the rate of 0.66 ml. of fumigant per cubic foot, no germination of cucumber and mustard seeds occurred when treated with water exposed to D-D. However, 92.5 percent of the cucumber seeds and 63.5 percent of the mustard seeds germinated when treated with the water exposed to the same concentration of Dowfume W-40. The seeds of cucumber were more resistant than mustard to the concentrations of fumigants which existed in the water exposed to the several concentrations.

Experiment No. 2. Effect of Absorption of Soil Fumigants by Water on the Subsequent Germination of Cucumber Seeds

2-A. pH of Water as Influenced by Soil Fumigants

In the previous experiment where water was exposed to soil fumigants and used in the germinative of seeds, evidence was shown that the vapors of fumigants could be absorbed partly by water and affect the germination capacity of seeds. A study was made to determine the possible change these vapors of D-D and Dowfume W-40 produce in water. Results of pH determinations indicated that the pH of water exposed to each fumigant was significantly different from the pH of water which had not been exposed to the fumigants. The results of the measurements of pH of 50 ml. of water

exposed to the soil fumigant treatments at three concentration levels for different periods of time is presented in Table 4. The fumigant, D-D, caused the greatest change in the pH of the exposed water. The use of Dowfume W-40 significantly reduced the pH of water, but not to the same extent as was found with D-D. Significant differences were found in the pH of water exposed to fumigants at the different concentrations. The higher the concentration of fumigant to which the water was exposed, the greater the increase in acidity of the water was found to be. It is shown in Table 5 that the pH of water was also influenced by the length of exposure to fumigants. Water exposed to fumigants for longer periods of time had a significantly lower pH than the water exposed for shorter periods of time. A significant interaction between concentration levels and the periods of exposure was found. The greater the concentration of fumigant and the longer the period of exposure of water to fumigant, the lower was the pH of water. It was also found that the soil fumigant treatments interacted with the concentration levels. This interaction is shown in Table 4. The exposure of water to increasing concentrations of D-D resulted in a sharp increase in the acidity of water. However, exposure of water to similar concentrations of Dowfume W-40 did not result in such an increase. Table 6 shows that the interaction between the

TABLE 4

THE pH OF 50 ML. OF WATER AS AFFECTED BY SOIL FUMIGANT TREATMENTS AT THREE CONCENTRATION LEVELS FOR THREE PERIODS OF TIME

Soil Fumigant Treatments	0.16 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	0.33 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	0.66 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	Average for Soil Fumigant Treatment
Non-fumigated	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.7	8.6	8.6
D-D	7.1	6.7	5.8	6.5	6.6	5.6	3.3	5.2	6.4	3.3	3.0	4.2	5.3
Dowfume W-40	8.4	8.1	7.8	8.1	8.1	7.9	7.6	7.9	7.8	7.7	7.5	7.7	7.9
Average for Concentration			7.7			7.2				6.8			

L.S.D. for soil fumigant treatment averages at: 5% level = 0.04, 1% level = 0.07

L.S.D. for concentration averages at: 5% level = 0.03, 1% level = 0.04

L.S.D. for individuals (Interaction) at: 5% level = 0.05, 1% level = 0.06

TABLE 5

EFFECT OF PERIODS OF EXPOSURE AND CONCENTRATION LEVELS ON THE pH OF 50 ML. OF WATER

Periods of Exposure (Hours)	Concentration of Fumigant (ml./5.ft.) 0.16	0.33	0.66	Average for Period of Exposure
12	8.0	7.8	7.6	7.8
24	7.8	7.4	6.5	7.2
48	7.4	6.5	6.4	6.7
L.S.D. for period of exposure averages at:			5% level = 0.03 1% level = 0.04	
L.S.D. for individuals (Interaction) at:			5% level = 0.05 1% level = 0.06	

TABLE 6

EFFECT OF SOIL FUMIGANT TREATMENTS AND PERIODS OF EXPOSURE ON THE pH OF 50 ML. OF WATER

Periods of Exposure (Hrs.)	Soil Fumigant Treatments: Non-Fumigated	D-D	Dowfume W-40
12	8.6	6.7	8.1
24	8.6	5.2	7.9
48	8.6	4.0	7.6
L.S.D. for individuals (Interaction) at:		5% level= 0.05 1% level =0.07	

fumigation treatments and length of exposure had a significant influence on the change of pH of water. The increasing periods of exposure of water to D-D markedly increased the acidity. The same periods of exposure to Dowfume W-40 increased the acidity of water, but not to the same degree as with D-D. The interaction between fumigation treatments, concentration levels, and periods of exposure was significant. The pH of 50 ml. of water as affected by the soil fumigant treatments at different concentration levels and for different periods of time is represented graphically in Fig. 1.

The pH determinations of 100 ml. of water as affected by soil fumigant treatments, three concentration levels, and periods of exposure are presented in the accompanying tables. The results obtained as a result of exposure of 100 ml. of water to soil fumigant treatments are not discussed, since the differences in pH found under different conditions were similar to those obtained with 50 ml. of water. Table 7 shows the pH determinations of 100 ml. of water as affected by soil fumigant treatments at three concentration levels for three periods of time. A significant interaction between fumigation treatments and concentration levels was found. The effect of different concentrations and periods of exposure to fumigants on the pH of 100 ml. of water is pre-

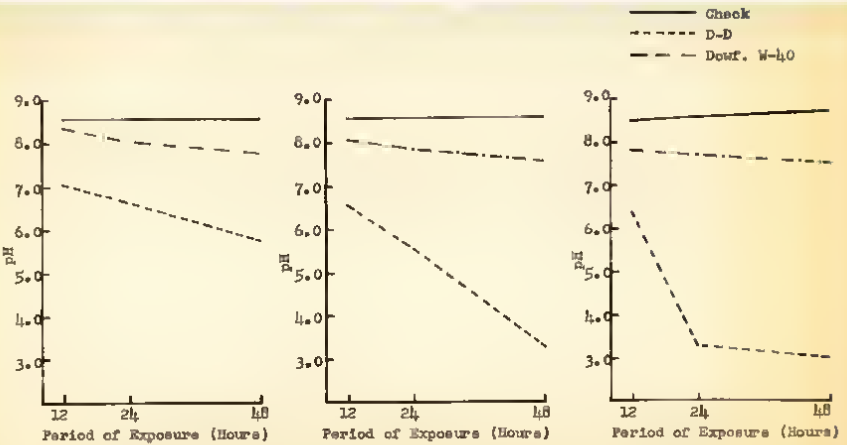


Fig. 1.--Effect of soil fumigant treatments, concentration levels, and periods of exposure on the pH of 50 ml. of water. Left to right, 0.16 ml., 0.33 ml., and 0.66 ml. per cubic foot.

TABLE 7

THE pH OF 100 ML. OF WATER AS AFFECTED BY SOIL FUMIGANT TREATMENTS AT THREE CONCENTRATION LEVELS FOR THREE PERIODS OF TIME

Soil Fumigant Treatments	0.16 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Ave.	0.33 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Ave.	0.66 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Ave.	Average for Soil Fumigant Treatment
Non-fumigated	8.5	8.5	8.6	8.5	8.6	8.5	8.5	8.5	8.5	8.6	8.6	8.6	8.5
D-D	7.4	6.9	6.7	7.0	6.9	6.3	5.6	6.3	6.7	4.5	3.3	4.8	6.0
Dowfume W-40	8.4	8.2	7.9	8.3	8.1	8.2	7.9	8.1	8.1	7.9	7.8	7.9	8.1
Average for Concentration		7.9				7.6				7.1			

L.S.D. for soil fumigant treatment averages at: 5% level = 0.04
1% level = 0.06

L.S.D. for concentration averages and L.S.D. for individuals (interaction) at: 5% level = 0.04
1% level = 0.05

sented in Table 8. The interaction between soil fumigant treatments and periods of exposure is presented in Table 9. There was a significant interaction between soil fumigant treatments, concentration levels, and periods of exposure. The pH determinations resulting from the exposure of 100 ml. of water to the soil fumigant treatments at the different concentration levels for different periods of time is represented graphically in Fig. 2.

It is evident from the data presented that the vapors of the fumigants are partly absorbed by water and change the pH of water. The fumigant, D-D, had a more significant influence on the pH of water than Dowfume W-40. The extent of influence of a fumigant on the change of pH of water depends upon the type of fumigant, its concentration, and the period of exposure.

The change in pH of 50 ml. of water as compared to 100 ml. of water as a result of exposure to soil fumigants at different concentration levels and for different periods of time is presented in Table 10. The results indicate that the pH change was significantly different between the two amounts of water exposed to fumigants. The pH of 50 ml. of water as a result of exposure to D-D and Dowfume W-40 at the three concentration levels for 24 and 48 hours was significantly lower than the pH of 100 ml. of water. However, there were no significant differences found in the pH be-

TABLE 8

EFFECT OF PERIODS OF EXPOSURE AND CONCENTRATION LEVELS OF SOIL FUMIGANTS ON THE pH OF 100 ML. OF WATER

Periods of Exposure (Hours)	Concentration of Fumigant (ml./s.ft.) 0.16	0.33	0.66	Average for Period of Exposure
12	8.1	7.9	7.8	7.9
24	7.9	7.7	7.0	7.5
48	7.7	7.3	6.6	7.2

L.S.D. for periods of exposure averages at: 5% level = 0.03
1% level = 0.04

L.S.D. for individuals (Interaction) at: 5% level = 0.06
1% level = 0.07

TABLE 9

EFFECT OF SOIL FUMIGANTS AND PERIODS OF EXPOSURE ON THE pH OF 100 ML. OF WATER

Period of Exposure (Hours)	Soil Fumigant Treatments: Non-fumigated	D-D	Dowfume W-40
12	8.5	7.0	8.2
24	8.5	5.9	8.1
48	8.6	5.2	7.9

L.S.D. for individuals (Interaction) at: 5% level = 0.05
1% level = 0.07

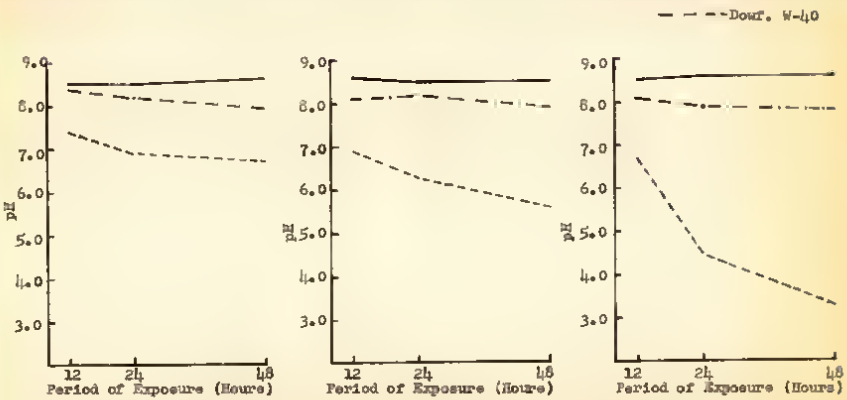


Fig. 2.--Effect of soil fumigant treatments, concentration levels, and periods of exposure on the pH of 100 ml. of water. Left to right, 0.16 ml., 0.33 ml., and 0.66 ml. per cubic foot.

TABLE 10

THE CHANGE IN pH OF 50 ML. OF WATER AS COMPARED TO THE CHANGE IN pH OF 100 ML. OF WATER AS A RESULT OF EXPOSURE TO SOIL FUMIGANTS AT DIFFERENT CONCENTRATIONS FOR 24 AND 48 HOURS

Concentration Ml./c.ft.	Period of Exposure (Hours)	D-D			Dowfume W-40		
		50 ml. Water	100 ml. Water	Shortest Significant Ranges (5% level) 2 Means	50 ml. Water	100 ml. Water	Shortest Significant Ranges (5% level) 2 Means
0.16	24	6.7	6.9	0.13	8.1	8.2	0.13
	48	5.8	6.7	0.13	7.8	7.9	(a)
0.33	24	5.6	6.3	0.13	7.9	8.2	0.13
	48	3.3	5.6	(a)	7.6	7.9	0.13
0.66	24	3.3	4.5	(a)	7.7	7.9	0.23
	48	3.0	3.3	0.13	7.5	7.8	0.13

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

(a) No experimental error

tween 50 and 100 ml. of water when exposed to Dowfume W-40 at 0.16 and 0.66 ml. per cubic foot for 24 hours.

It is noticed that pH values obtained by exposure of 50 ml. of water to D-D at each concentration for 24 hours were found to be the same as those obtained with 100 ml. of water exposed for 48 hours for the same concentrations. The smaller quantities of water absorb vapor faster than the larger quantities.

The analysis of variance for the pH of 50 and 100 ml. of water exposed to the soil fumigant treatments at different concentration levels for different periods of time is presented in Table 11.

Experiment No. 2-B. Effect of Water Exposed to Soil Fumigants on the Germination of Cucumber Seeds

The water which had been exposed to the soil fumigants in the previously described experiment was used as a source of water for cucumber seeds. The germination of cucumber seeds as influenced by watering with portions of a 50 ml. sample of water that had been exposed to soil fumigant treatments at three concentration levels for three periods of time is presented in Table 12. The data on the percentage germination show that the differences were significant between the seeds treated with fumigated water and those treated with non-fumigated water. The water exposed to D-D was found to be more toxic than the

TABLE 11

ANALYSIS OF VARIANCE FOR THE pH OF 50 AND 100 ML. OF WATER EXPOSED TO SOIL FUMIGANT TREATMENTS AT THREE CONCENTRATION LEVELS FOR THREE PERIODS OF TIME

Sources of Variation	D.F.	Sum Squares	
		50 ml. of Water	100 ml. of Water
Grand Total	107	303.91	186.73
Main Treatments	11	214.34	128.55
Soil Fumigants	2	214.29(xx)	128.51(xx)
Replications	3	0.02	0.01
Error (a)	6	0.03	0.03
Exposure Treatments	24	44.77	20.59
Period of Exposure	2	18.78(xx)	9.22(xx)
Exposure x Soil Fum.	4	25.93(xx)	11.32(xx)
Error (b)	18	0.06	0.05
Concentration Treatments	72	44.80	37.59
Concentrations	2	15.08(xx)	11.47(xx)
Concs. x Soil Fum.	4	17.41(xx)	16.92(xx)
Concs. x Periods of Exposure	4	3.68(xx)	2.77(xx)
Concs. x Fum. x Periods of Exposure	8	8.44(xx)	6.18(xx)
Error (c)	54	0.19	0.25

(a) Significant at 5% level
(xx) Significant at 1% level

TABLE 12

THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS AS AFFECTED BY 50 ML. OF WATER EXPOSED TO SOIL FUMIGANT TREATMENTS

Soil Fumigant Treatments	0.16 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	0.33 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	0.66 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	Average for Soil Fumigant Treatment
Non-fumigated	93.0	97.0	95.0	95.0	97.0	94.5	96.0	95.8	93.0	90.5	92.5	92.0	94.3
D-D	93.5	57.0	34.5	61.7	60.0	0.5	0.0	20.2	34.5	0.0	0.0	11.5	30.5
Dowfume W-40	93.0	87.5	85.0	88.5	94.0	83.0	84.0	87.0	91.0	83.5	89.5	88.0	87.8
Average for Concentration		81.7				67.7				63.2			

L.S.D. for soil fumigant treatment averages at: 5% level = 2.2, 1% level = 3.3

L.S.D. for concentration averages at: 5% level = 1.7, 1% level = 2.2

L.S.D. for individuals (Interaction) at: 5% level = 2.9, 1% level = 3.8

water exposed to Dowfume W-40. Significant differences in the percentage germination of seeds were found when the water exposed at different concentrations was applied to seeds. The higher the concentration of fumigant to which the water was exposed the greater the injury to the germinating ability. It was found from Table 13 that the germination of cucumber seeds was also affected by the length of time the water was exposed to fumigants. The water exposed to fumigants for longer periods of time reduced the germination percentage significantly more when applied to seeds than the water exposed for shorter periods of time. It was found that the periods of exposure interacted with the concentration levels. The average germination of seeds with water exposed to the increasing concentrations of fumigant for 12 hours was significantly reduced. The water exposed to fumigants at 0.33 and 0.66 ml. per cubic foot for 24 and 48 hours when applied to seeds reduced the germination percentage significantly more than when the water was exposed for only 12 hours. However, there were no differences found in the germination percentage of seeds when treated with the water exposed at concentrations of 0.33 and 0.66 ml. per cubic foot for 24 hours and 48 hours. It was also found that the soil fumigant treatments interacted with the concentration levels. This interaction is shown in Table 12. The water exposed to increasing concentrations of D-D when

TABLE 13

EFFECT OF 50 ML. OF WATER EXPOSED AT DIFFERENT CONCENTRATIONS FOR DIFFERENT PERIODS OF TIME ON THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS

Periods of Exposure (Hours)	Concentration of Fumigant (ml./c.ft.) 0.16	0.33	0.66	Average for Period of Exposure
12	93.2	83.7	72.8	82.6
24	80.5	59.3	58.0	65.9
48	71.5	60.0	60.8	64.1

L.S.D. for period of exposure averages at: 5% level = 1.5, 1% level = 2.1

L.S.D. for individuals (Interaction) at: 5% level = 2.9, 1% level = 3.8

TABLE 14

EFFECT OF 50 ML. OF WATER EXPOSED TO SOIL FUMIGANT TREATMENTS FOR DIFFERENT PERIODS OF TIME ON THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS

Periods of Exposure (Hours)	Soil Fumigant Treatments Non-fumigated	D-D	Dowfume W-40
12	94.3	60.8	92.7
24	94.0	19.2	84.7
48	94.5	11.5	86.2

L.S.D. for individuals (Interaction) at: 5% level = 2.6, 1% level = 3.5

applied to seeds resulted in an increasingly lower germination. No significant differences were found in the germination of seeds when the water which had been exposed to similar concentrations of Dowfume W-40 was applied to seeds. Table 14 shows the interaction between soil fumigant treatments and different periods of exposure. The average germination resulting from the use of water exposed to D-D for increasing periods of time was increasingly reduced. The water exposed to Dowfume W-40 for 24 and 48 hours when applied to seeds resulted in a lower germination than the water exposed for 12 hours. However, there were no differences between exposure for 24 and for 48 hours. The interaction between soil fumigant treatments, concentration levels, and periods of exposure was statistically significant. The percent of seeds killed when 50 ml. of water exposed to soil fumigants was used as a source of water for the seeds is represented graphically in Fig. 3.

The effect on the germination of cucumber seeds as a result of the toxicity of 100 ml. of water which had been exposed to soil fumigant treatments at three concentration levels for three periods of time is presented in Table 15. Significant differences were found in the percentage germination between the seeds treated with water exposed to D-D and non-fumigated water, but no differences in germination were observed between the seeds treated with water

Fig. 3.—Effect of water exposed to soil fumigants on the germination of cucumber seeds. Top, 50 ml. of water. Left to right: 0.16, 0.33, and 0.66 ml. of fumigants per cubic foot. Bottom, 100 ml. of water. Left to right: 0.16, 0.33, and 0.66 ml. of fumigants per cubic foot.

———— Check

- - - - D-D

—·—·— Dowfume W-40

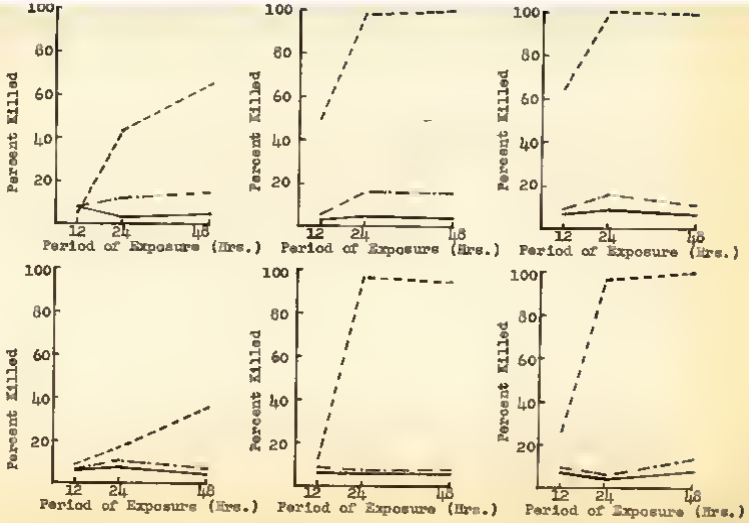

Percent Killed
100
80
60
40
20
12
24
48
Period of Exposure (Hrs.)

TABLE 15

THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS AS AFFECTED BY 100 ML. OF WATER EXPOSED TO SOIL FUMIGANT TREATMENTS

Soil Fumigant Treatments	0.16 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	0.33 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	0.66 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	Average for Soil Fumigant Treatment
Non-fumigated	93.5	92.0	95.0	93.5	93.5	94.0	93.0	93.5	92.0	95.0	91.0	92.7	93.2
D-D	91.5	82.5	64.0	79.3	86.5	3.0	4.5	31.3	71.5	3.3	0.0	24.9	45.2
DowFume W-40	93.0	88.5	93.0	91.5	90.5	93.5	93.0	92.3	90.5	93.5	86.0	90.0	91.3
Average for Concentration		88.1				72.4				69.2			

L.S.D. for soil fumigant treatment averages at: 5% level = 2.1, 1% level = 3.2

L.S.D. for concentration averages at: 5% level = 1.7, 1% level = 2.3

L.S.D. for individuals (Interaction) at: 5% level = 3.0, 1% level = 4.0

exposed to Dowfume W-40 and those treated with non-fumigated water. In comparing D-D with Dowfume W-40, the water which had been exposed to D-D was found to be more toxic. The germination of seeds obtained as a result of using water exposed to different concentrations was also significantly different. Table 16 shows that the differences found in the germinative percentages when watered with water exposed to soil fumigant for different periods of time were significant. The longer the period of exposure of water to fumigant, the greater the injury caused to the germination of seeds. A significant interaction between the three concentration levels and the three periods of exposure was found. The exposure of water to fumigant at 0.16 and 0.66 ml. per cubic foot for the increasing periods of time resulted in a steady decrease in germination. It was found that the soil fumigant treatments interacted with the concentration levels. This interaction is shown in Table 15. The exposure of water to increasing concentrations of D-D resulted in an increasing lowering of germination. However, there were no differences found in germination percentage when water exposed to similar concentrations of Dowfume W-40 was used to water the seeds. Table 17 shows the interaction between the soil fumigant treatments and periods of exposure. The exposure of water to D-D for increasing periods of time increasingly reduced the germi-

TABLE 16

EFFECT OF 100 ML. OF WATER EXPOSED AT DIFFERENT CONCENTRATIONS OF SOIL FUMIGANTS FOR DIFFERENT PERIODS OF TIME ON THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS

Periods of Exposure (Hours)	Concentration of Fumigant (ml./c.ft.)			Average for Period of Exposure
	0.16	0.33	0.66	
12	92.7	90.2	84.7	89.2
24	87.7	63.5	63.9	71.7
48	84.0	63.5	59.0	68.8

L.S.D. for period of exposure averages at: 5% level = 1.5
1% level = 2.1

L.S.D. for individuals (Interaction) at: 5% level = 3.0
1% level = 4.0

TABLE 17

EFFECT OF 100 ML. OF WATER EXPOSED TO SOIL FUMIGANTS FOR DIFFERENT PERIODS OF TIME ON THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS

Periods of Exposure (Hours)	Soil Fumigant Treatments		
	Non-fumigated	D-D	Dowfume W-40
12	93.0	83.2	91.3
24	93.7	29.6	91.8
48	93.0	22.8	90.7

L.S.D. for individuals (Interaction) at: 5% level = 2.6
1% level = 3.5

nation percentage of seeds. Exposure of water to Dowfume W-40 for the same periods of time did not show any influence on the germination of seeds. A significant interaction between the soil fumigant treatments, concentration levels, and periods of exposure was found. The percent of seeds apparently killed when 100 ml. of water exposed to fumigants was used as a source of water for the seeds is represented graphically in Fig. 3.

In general the water exposed to fumigants and subsequently used for germinating the seeds was found to be toxic, with water exposed to D-D having a more toxic effect than that exposed to Dowfume W-40. The toxicity of water exposed to D-D was directly proportional to the concentration and the period of exposure, but this was not true with the water exposed to Dowfume W-40, although the toxicity of this material to germinating seeds was noticed with water exposed at higher concentrations and for longer periods of time.

Adams (1) reported coagulation of protoplasm of root hairs of wheat at a pH of 4.0 or below, and Lewis (29) found coagulation of cytoplasm and nuclei of embryonic cells at a pH of 4.6 The inhibition of root hair development of seedlings was observed in this experiment when water exposed at higher concentrations of the fumigant was used to germinate the seeds.

Table 18 shows the percentage of abnormal seedlings found as a result of using 50 ml. of water which had been exposed to different concentrations of soil fumigants for different periods of time to water cucumber seeds. The data show that there were significant differences. The percent of abnormal seedlings found as a result of using water exposed to D-D at the three concentration levels and for different periods of time was usually significantly higher as compared to the water exposed to Dowfume W-40 and non-exposed water. However, no significant differences were found in the percent of abnormal seedlings when water was exposed to D-D and Dowfume W-40 at 0.16 ml. per cubic foot for 12 hours. The percent of abnormal seedlings found was in direct proportion to the concentration and to the length of time the water was exposed to D-D. The water exposed to Dowfume W-40 at different concentrations for 24 and 48 hours when used to water the cucumber seeds also resulted in a significantly higher percentage of abnormal seedlings than the water not exposed to fumigants, but this was not true for 12 hour exposure periods.

Table 19 shows the analysis of variance for the percentage germination of cucumber seeds as influenced by 50 and 100 ml. of water exposed to soil fumigant treatments at three concentration levels and for three periods of time.

TABLE 18

PERCENTAGE ABNORMAL SEEDLINGS RESULTING FROM USING 50 ML. OF WATER EXPOSED TO DIFFERENT CONCENTRATIONS OF SOIL FUMIGANTS FOR DIFFERENT PERIODS OF TIME AS A SOURCE OF WATER FOR CUCUMBER SEEDS

Periods of Exposure (Hours)	Percent of Abnormal Seedlings			Shortest Significant Ranges (5% level)	
	Check	Dowfume W-40	D-D	2 Means	3 Means
		Concn. 0.16 ml./c.ft.			
12	3.5	4.0	3.5	3.0	3.1
24	3.0	12.5	36.5	5.3	5.5
48	2.5	11.0	57.5	4.0	4.2
		Concn. 0.33 ml./c.ft.			
12	2.5	4.0	36.0	5.4	5.6
24	3.0	12.6	84.5	5.4	5.5
48	2.0	12.5	84.0	9.3	9.5
		Concn. 0.66 ml./c.ft.			
12	3.5	4.0	65.0	5.4	5.5
24	4.5	12.0	87.0	3.6	3.7
48	3.5	12.5	93.0	7.7	7.9

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

TABLE 19

ANALYSIS OF VARIANCE FOR THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS AS AFFECTED BY THE USE OF PORTIONS OF 50 AND 100 ML. OF WATER EXPOSED TO SOIL FUMIGANT TREATMENT AT THREE CONCENTRATION LEVELS FOR THREE PERIODS OF TIME

Sources of Variance	D.F.	Sum Squares	
		50 ml. of Water	100 ml. of Water
Grand Total	107	78986.13	61860.87
Main Treatments	11	52127.02	30957.44
Soil Fumigants	2	52030.14(xx)	30800.16(xx)
Replications	3	13.69	75.38
Error (a)	6	83.19	81.90
Exposure Treatments	24	12462.86	14701.54
Period of Exposure	2	5535.15(xx)	4517.19(xx)
Exposure x Soil Fum.	4	6763.14(xx)	10020.58(xx)
Error (b)	18	164.57	163.77
Concentration Treatments	72	14396.25	16201.89
Concentrations	2	4833.04(xx)	3942.41(xx)
Concs. x Soil Fum.	4	7922.70(xx)	7906.41(xx)
Concs. x Periods of Exposure	4	693.28(xx)	927.38(xx)
Concs. x Soil Fum. x Periods of Exposure	8	280.53(xx)	2694.83(xx)
Error (c)	54	666.70	730.86

(x) Significant at 5% level

(xx) Significant at 1% level

Experiment No. 2-C. Effect of Aeration of Water Exposed to D-D on the Germination of Cucumber Seeds

The germination of cucumber seeds as influenced by using water exposed to D-D at three concentration levels and three periods of time is presented in Table 20. A sample of 50 ml. of water was used for each treatment. The water was applied by three methods--immediately after fumigation, and after aeration for one and two weeks prior to application to the seeds. The data show that significant differences were found in the germination percentage between the seeds treated with aerated and non-aerated water. The differences in percentage germination found as a result of using water exposed at different concentrations were significant. It is seen from Table 21 that the period of exposure of water to fumigants had a significant influence on the germination of seeds. The longer the period of exposure of water to the fumigant, the greater the injury found to the germinating ability of seeds. A significant interaction between concentration levels and periods of exposure was found. The germination percentage of seeds found as a result of using water which had been exposed at 0.16, 0.33, and 0.66 ml. per cubic foot for increasing periods of time was increasingly reduced. It was found that the period of aeration interacted with the concentration levels. This interaction is shown in Table 20.

TABLE 20

THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS AS AFFECTED BY PERIOD OF AERATION OF 50 ML. OF WATER EXPOSED AT DIFFERENT CONCENTRATIONS OF D-D FOR DIFFERENT PERIODS OF TIME

Periods of Aeration	0.16 ml./0.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	0.33 ml./0.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	0.66 ml./0.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Avg.	Average For Period of Aeration
Non-aerated	93.5	57.0	34.5	61.7	60.0	0.5	0.0	20.2	29.0	0.0	0.0	9.7	30.5
Aerated 1 Week	93.5	89.5	90.0	91.0	89.0	89.5	48.0	75.5	89.0	86.5	42.0	72.5	79.7
Aerated 2 Weeks	93.0	93.0	92.0	92.7	92.0	91.8	89.0	90.9	92.0	92.0	81.5	88.5	90.7
Average for Concentration		81.8				62.2				56.9			

L.S.D. for period of aeration averages at: 5% level = 1.4, 1% level = 2.1

L.S.D. for concentration averages at: 5% level = 1.4, 1% level = 1.9

L.S.D. for individuals (Interaction) at: 5% level = 2.9, 1% level = 3.9

TABLE 21

THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS AS INFLUENCED BY WATER (50 ML.) EXPOSED TO THREE CONCENTRATIONS OF D-D FOR THREE PERIODS OF TIME

Periods of Exposure (Hours)	Concentration of Fumigant (ml./c.ft.)			Average for Period of Exposure
	0.16	0.33	0.66	
12	93.3	80.3	70.0	81.2
24	79.8	60.6	59.5	66.7
48	72.2	45.7	41.2	53.0

L.S.D. for period of exposure averages at: 5% level = 0.8
1% level = 1.1

L.S.D. for individuals (Interaction) at: 5% level = 2.9
1% level = 3.9

TABLE 22

EFFECT OF PERIOD OF AERATION OF 50 ML. OF WATER EXPOSED TO D-D FOR THREE PERIODS OF TIME ON THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS

Periods of Exposure (Hours)	Periods of Aeration		
	Non-aerated	Aerated 1 Week	Aerated 2 Weeks
12	60.8	90.5	92.3
24	19.2	88.5	92.3
48	11.5	60.0	87.5

L.S.D. for individuals (Interaction) at: 5% level = 1.4
1% level = 1.9

With increase in period of aeration of water which had been exposed to 0.16, 0.33, and 0.66 ml. per cubic foot, the germination percentage of seeds was significantly increased. However, no significant difference in germination was found when water exposed at 0.16 ml. per cubic foot was aerated for one and two weeks and applied to seeds. Table 22 shows the interaction between periods of exposure and periods of aeration. The increasing periods of aeration of water which had been exposed to fumigants for 12 and 24 hours increased the percentage germination of seeds. Similar periods of aeration of water which had been exposed to fumigant for 48 hours increased the germination percentage of seeds but not to the same degree as was found in the case of exposures for 12 and 24 hours. It appears that if the initial germination was reduced with the non-aerated water, probably longer periods of aeration would be necessary to reduce the toxicity of water to seeds. A significant interaction was found between the periods of aeration, concentration levels, and periods of exposure. The increase in the number of seeds killed by the lack of adequate aeration is represented graphically in Fig. 4.

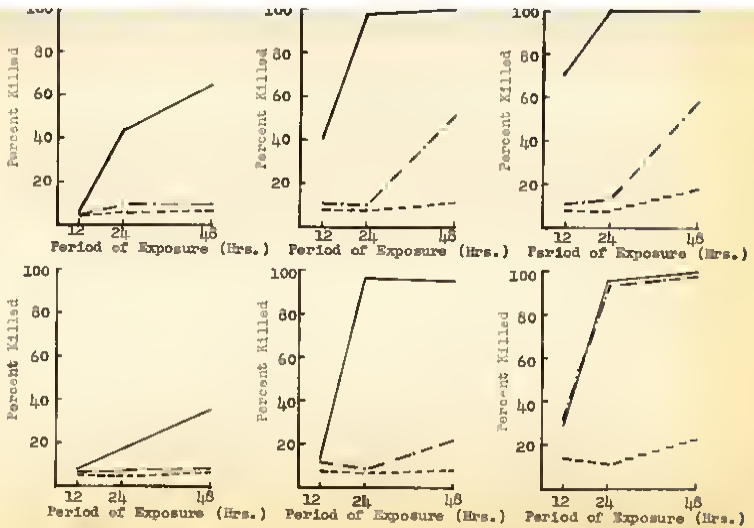
The pH of water exposed to D-D and aerated for one and two weeks was the same as that of water which had not been exposed.

Fig. 4.--Effect of aeration on the toxicity of water exposed to D-D when used for watering germinating cucumber seeds. Top, 50 ml. of water. Left to right: 0.16, 0.33, and 0.66 ml. per cubic foot of D-D. Bottom, 100 ml. of water. Left to right: 0.16, 0.33, and 0.66 ml. per cubic foot of D-D.

———— Non-aerated

—·—·— Aerated 1 Week

- - - - Aerated 2 Weeks


Percent Killed
100
80
60
40
20
12
24
48
Period of Exposure (Hrs.)

The germination percentages resulting from the use of portions of 100 ml. of water which had been exposed to D-D at different concentration levels for different periods of time and portions of this water aerated for one and two weeks are presented in Tables 23, 24, and 25. The results obtained as a result of using portions of 100 ml. of water are not discussed in detail since the differences in the germination percentages found under different conditions were identical with those obtained with 50 ml. of water. Table 23 shows the percentage germination of cucumber seeds as influenced by aeration of water which had been exposed to different concentrations of D-D. A significant interaction between concentration levels and periods of aeration was found. The germination of cucumber seeds as influenced by use of portions of 100 ml. of water which had been exposed at different concentrations for different periods of time and the interaction between these two factors is presented in Table 24. The interaction between period of aeration and period of exposure is presented in Table 25. A significant interaction between periods of aeration, concentration levels, and periods of exposure was also found. The percent of seeds apparently killed by lack of adequate aeration is represented graphically in Fig. 4.

TABLE 23

THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS AS AFFECTED BY PERIOD OF AERATION OF 100 ML. OF WATER EXPOSED AT DIFFERENT CONCENTRATIONS OF D-D FOR DIFFERENT PERIODS OF TIME

Periods of Aeration	0.16 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Ave.	0.33 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Ave.	0.66 ml./c.ft. 12 Hrs.	24 Hrs.	48 Hrs.	Ave.	Average for Period of Aeration
Non-aerated	91.5	82.5	64.0	79.3	86.5	3.0	4.5	31.3	71.5	3.3	0.0	24.9	45.2
Aerated 1 Week	92.8	92.0	92.0	92.3	92.8	91.0	77.5	86.8	70.0	5.0	0.5	25.2	68.1
Aerated 2 Weeks	94.0	94.3	92.5	93.6	91.5	91.3	92.0	91.6	85.5	88.5	76.5	83.5	89.6
Average for Concentration			88.4				69.9				44.5		

L.S.D. for period of aeration averages at: 5% level = 2.3, 1% level = 3.6

L.S.D. for concentration averages at: 5% level = 1.6, 1% level = 2.2

L.S.D. for individuals (Interaction) at: 5% level = 2.8, 1% level = 3.7

TABLE 24

EFFECT OF 100 ML. OF WATER EXPOSED AT THREE CONCENTRATION LEVELS FOR THREE PERIODS OF TIME ON THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS

Periods of Exposure (Hours)	Concentration of Fumigant (Ml./c.ft.)			Average for Period of Exposure
	0.16	0.33	0.66	
12	92.8	89.6	82.8	86.1
24	90.0	61.8	58.0	61.2
48	75.7	32.3	25.7	55.5
L.S.D. for period of exposure averages at:				5% level=1.7 1% level=2.4
L.S.D. for individuals (Interaction) at:				5% level=2.9 1% level=3.7

TABLE 25

EFFECT OF PERIOD OF AERATION OF 100 ML. OF WATER EXPOSED TO D-D FOR THREE PERIODS OF TIME ON THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS

Periods of Exposure (Hours)	Period of Aeration		
	Non-aerated	Aerated 1 Week	Aerated 2 Weeks
12	83.2	84.9	90.3
24	29.6	62.7	91.4
48	22.8	56.7	87.0
L.S.D. for individuals (Interaction) at:			5% level = 3.0 1% level = 4.1

The pH determinations of 100 ml. of water which were made after one week and two weeks of aeration was found to be the same as those of non-aerated water.

Table 26 shows the analysis of variance for the percentage germination of cucumber seeds as affected by the different periods of aeration using 50 and 100 ml. of water exposed to D-D at the three concentration levels for the three periods of time.

Experiment No. 3. Germination of Various Seeds as Affected by the pH of Water

The main purpose of this experiment was to study the effect of pH of water on the germination of seeds as related to the change in pH of water by soil fumigants. The germination percentages of various seeds reported in Table 27 did not indicate any evidence of toxicity of pH of the water used. The seeds to which water whose pH had been adjusted with hydrochloric acid was applied, germinated equally as well as to those to which only tap water was applied.

It was also evident from the previous experiment that the toxicity of water exposed to D-D on the germination of seeds was not due to the change in pH of water. If the reduced germination had been due to the low pH of water, no increased germination could be expected after an aeration of two weeks, since the pH determinations of this

TABLE 26

ANALYSIS OF VARIANCE FOR THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS AS AFFECTED BY AERATION OF 50 AND 100 ML. OF WATER EXPOSED TO D-D AT THREE CONCENTRATION LEVELS FOR THREE PERIODS OF TIME

Sources of Variation	D.F.	Sum Squares	
		50 ml. of Water	100 ml. of Water
Grand Total	107	73860.06	77601.37
Main Treatments	11	42331.04	19859.44
Periods of Aeration	2	42287.10(xx)	19736.46(xx)
Replications	3	9.57	24.70
Error (a)	6	34.37	98.28
Exposure Treatments	24	15150.09	18119.67
Periods of Exposure	2	8656.76(xx)	10936.00(xx)
Exposure x Periods of Aeration	4	6443.28(xx)	6965.81(xx)
Error (b)	18	50.05	217.86
Concentration Treatments	72	16378.93	39622.26
Concentrations	2	7971.43(xx)	20700.65(xx)
Concen. x Periods of Aeration	4	5828.14(xx)	10559.92(xx)
Concen. x Periods of Exposure	4	537.74(xx)	3802.75(xx)
Concen. x Periods of Aeration x Periods of Exposure	8	1562.45(xx)	3911.84(xx)
Error (c)	54	479.17	646.90

(x) Significant at 5% level

(xx) Significant at 1% level

TABLE 27

EFFECT OF pH OF WATER ON THE GERMINATION OF VARIOUS SEEDS

Crop Seeds	Average Percentage Germination	
	Tap Water pH (8.5)	Hydrochloric Acid Solution, pH (3.1)
Cucumber	91.5	96.5
Cabbage	72.5	76.5
Lettuce	96.0	96.8
Mustard	75.0	68.8
Oats	83.0	78.5
Rye	86.0	88.0

water made after an aeration of two weeks remained the same as that of non-aerated water. But a significant increase in germination percentage was found when water aerated for two weeks was applied to seeds as compared to the non-aerated water. Also if the lowering of pH of water exposed to D-D had been due to the vapors of fumigant being dissolved in water, a change in pH could be expected after an aeration period of two weeks, since the toxicity of water on germination was reduced on aeration for two weeks, presumably due to the escape of vapors from the water. But this was not the case and no pH change was found. It is also well known that the dichloropropenes and dichloropropane are hydro-

carbons and are nontoxic. Hence the toxicity of water exposed to D-D might possibly be due to the hydrolysis of D-D.

Experiment No. 4. Effect of Soil Fumigants on Dry Cucumber Seeds

The effect of exposure to D-D on dry cucumber seeds and the subsequent effects of aeration of a portion of the fumigated seed for a period of ten days on the germination of seeds are shown in Table 28. The data indicate that significant differences were found between the seeds germinated immediately after fumigation and those germinated after an aeration period of ten days at most of the lower concentrations. The seeds exposed to higher concentrations of the fumigant did not germinate even after aeration. It is noted that the germination percentages of the seeds exposed to 3.3 ml. of fumigant per cubic foot for 3, 5, and 7 days were considerably reduced when it was attempted to germinate them immediately after fumigation; but after an aeration period of ten days, 78.0 and 66.5 percent of the seeds germinated in the case of those exposed for 3 and 5 days, respectively. No germination occurred in the case of those seeds exposed for 7 days, indicating that the time of exposure is the limiting factor in the fumigation of dry seeds at this concentration. It could also be noted from

TABLE 28

THE GERMINATION PERCENTAGE OF CUCUMBER SEEDS AS AFFECTED BY CONCENTRATION OF D-D, LENGTH OF EXPOSURE AND AERATION

Period of Exposure (Days)	Non-aerated	Aerated 10 days	Check	Shortest Significant Ranges (5% level) 2 Means	3 Means
	Concn. 1.98 ml./c.ft.				
3	83.5	92.0	91.0	3.5	3.6
5	69.0	91.5	89.5	5.5	5.7
7	53.0	71.5	90.5	3.2	3.3
	Concn. 2.64 ml./c.ft.				
3	79.0	93.0	93.0	4.7	4.9
5	63.0	88.5	93.5	3.8	3.9
7	8.8	12.5	90.0	5.6	5.8
	Concn. 3.30 ml./c.ft.				
3	9.0	78.0	90.0	4.7	4.9
5	7.0	66.5	93.0	2.7	2.8
7	0.0	0.0	90.0	—	—
	Concn. 6.60 ml./c.ft.				
3	0.0	0.0	89.0	—	—
5	0.0	0.0	89.0	—	—
7	0.0	0.0	89.0	—	—

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

the foregoing table that with seeds exposed for 7 days at lower concentrations and with those exposed to a concentration greater than 2.64 ml. of fumigant per cubic foot, irrespective of time of exposure, normal germination could not be restored on aeration. In general, the germination percentage of seeds is in inverse proportion to the concentration and time of exposure to the fumigant when germination is attempted before aeration.

Table 29 shows the influence of Dowfume W-40 on the immediate germination of dry cucumber seeds as compared to the germination following the aeration of a portion of these seeds after exposure. The results indicate that the differences found in the percentage germination are significant between non-aerated and aerated seed, except when the seeds were exposed to 1.98 ml. per cubic foot for 3 days. Normal germination was not restored with the seeds exposed at 3.3 and 6.6 ml. per cubic foot for 7 days. In all other cases, normal germination of seeds was restored on aeration irrespective of concentration and period of exposure.

Even though an statistical analysis is shown for comparing D-D with Dowfume W-40, it is noted from the results that D-D appears to be more toxic than Dowfume W-40. When the seeds were exposed to D-D at concentrations of 3.3 ml. per cubic foot for 7 days and 6.6 ml. per cubic

TABLE 29

THE GERMINATION PERCENTAGE OF CUCUMBER SEEDS AS AFFECTED BY CONCENTRATION OF DOWFUME W-40, LENGTH OF EXPOSURE, AND AERATION

Periods of Exposure (Days)	None aerated	Aerated 10 Days	Check	Shortest Significant Ranges (5% level) 2 Means	3 Means
	Concn. 1.98 ml./c.ft.				
3	89.0	92.0	91.0	4.1	4.2
5	68.5	89.5	89.5	5.8	6.0
7	62.5	89.0	90.5	4.0	4.2
	Concn. 2.64 ml./c.ft.				
3	87.0	91.5	93.0	4.2	4.3
5	60.5	89.0	93.5	6.1	6.3
7	40.0	80.5	90.0	3.6	3.8
	Concn. 3.30 ml./c.ft.				
3	50.5	84.5	90.0	6.2	6.4
5	41.0	89.0	93.0	6.0	6.2
7	40.0	80.5	90.0	3.6	3.8
	Concn. 6.60 ml./c.ft.				
3	26.0	90.0	89.0	5.3	5.5
5	30.5	89.5	89.0	3.5	3.7
7	29.5	76.5	89.0	4.5	4.6

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

foot for 3, 5, and 7 days, the germination quality of seeds was destroyed even after aeration. However, the seeds which were exposed for the same period of time and concentration of Dowfume N-40 germinated at a rate similar to untreated seeds on aeration.

It can be concluded that both D-D and Dowfume N-40 had marked influence upon the germination ability of air-dried cucumber seeds. The extent of the influence of each fumigant depended upon the concentration of the fumigant and upon the time the seeds were exposed. Delay in germination was noted due to the treatment in all cases when germination was attempted before aeration. It is noted from the results that when no germination occurred after aeration, the germination ability of seeds was destroyed before aeration. This was found with D-D at concentrations of 3.3 ml. for 7 days and 6.6 ml. for 3, 5, and 7 days.

The above-mentioned observations substantiate the results obtained with dry seeds by others. Townsend (57, 58) reported that dry seeds were affected by hydrocyanic acid gas and other, the toxicity again depending upon the duration of exposure and concentration of fumigant. Moore (37) working with chloropicrin and Cannon (16) working with methyl bromide reported that germination of seeds was retarded if germination was attempted before thorough aeration.

Experiment No. 5. Effect of Soil Fumigants on Damp Seeds

Cucumber

The germination of cucumber seeds soaked in water for 12 hours before treatment as influenced by exposure to soil fumigant treatments at three concentration levels and periods of time is presented in Table 30. The percentage germination of treated seeds was significantly lower than the germination of non-treated seeds. In comparing the effect of D-D with Dowfume W-40, the seeds treated with D-D had a significantly lower germination than the seeds treated with Dowfume W-40. The average concentration of soil fumigant to which the seeds were exposed had a significant influence on the germination of seeds. The seeds exposed to higher concentrations of fumigant had a significantly lower germination than the seeds exposed at lower concentrations. Table 31 shows that the germination of seeds was effected by the length of time the seeds were exposed to the fumigant. The longer the period of exposure, the greater the reduction found in the germinating ability of seeds. A significant interaction was found between the concentration levels and the periods of exposure. The exposure of seeds to the increasing concentrations of fumi-

TABLE 30

THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS SOAKED FOR 12 HOURS AS INFLUENCED BY EXPOSURE TO SOIL FUMIGANT TREATMENTS, CONCENTRATION LEVELS AND PERIODS OF TIME

Soil Fumigant Treatment	0.66 ml./c.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Avg.	1.32 ml./c.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Avg.	1.98 ml./c.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Avg.	Average for Soil Fumigant
Non-fumigated	94.5	98.0	97.5	96.7	92.5	97.5	97.5	95.8	96.5	97.5	94.0	96.0	96.2
D-D	79.0	77.0	73.0	76.3	81.5	15.8	0.0	32.4	52.0	0.0	0.0	17.3	42.0
Dowfume W-40	97.5	97.0	94.0	96.1	98.5	92.5	91.0	94.0	95.0	84.5	65.5	81.7	90.6
Average for Concentration		89.7				74.1				65.0			

L.S.D. for soil fumigant treatment averages at: 5% level = 2.1, 1% level = 3.2

L.S.D. for concentration averages at: 5% level = 1.5, 1% level = 2.1

L.S.D. for individuals (Interaction) at: 5% level = 2.7, 1% level = 3.6

TABLE 31

EFFECT OF CONCENTRATION LEVELS AND PERIODS OF EXPOSURE ON THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS SOAKED FOR 12 HOURS

Periods of Exposure (Hours)	Concentration of Fumigant (ml./0.ft.)			Average for Period of Exposure
	0.66	1.32	1.98	
2	90.3	90.8	81.2	87.4
4	90.7	68.6	60.7	73.3
6	68.2	62.8	53.2	68.0

L.S.D. for period of exposure averages at: 5% level = 2.1
1% level = 2.8

L.S.D. for individuals (Interaction) at: 5% level = 2.7
1% level = 3.6

TABLE 32

THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS SOAKED FOR 12 HOURS AS AFFECTED BY THREE PERIODS OF EXPOSURE TO SOIL FUMIGANT TREATMENTS

Periods of Exposure (Hours)	Soil Fumigant Treatments		
	None fumigated	D-D	Dowfume W-40
2	94.5	70.8	97.0
4	97.7	30.9	92.3
6	96.3	24.3	83.5

L.S.D. for individuals (Interaction) at: 5% level = 3.6
1% level = 4.9

gant for four and six hours significantly reduced the percentage germination of seeds. No significant difference in germination was found between the seeds exposed at 0.66 and 1.32 ml. per cubic foot for two hours. The three concentration levels interacted with the soil fumigant treatments as shown in Table 30. The exposure of seeds to increasing concentrations of D-D resulted in a successive lowering of germination. Exposure of seeds to Dowfume W-40 reduced the germination only at a concentration of 1.98 ml. per cubic foot. A significant interaction between periods of exposure and soil fumigant treatments was found. This interaction is shown in Table 32. The increasing periods of exposure of damp cucumber seeds to D-D increasingly reduced the germination of seeds. Exposure of seeds to Dowfume W-40 for the same periods of time resulted in decreases of germination but not to such an extent as was found with D-D. A significant interaction between soil fumigant treatments, concentration levels, and periods of exposure was also found. The percent of seeds killed by exposing the damp seeds to each fumigant at different concentration levels for the three periods of time is represented graphically in Fig. 5.

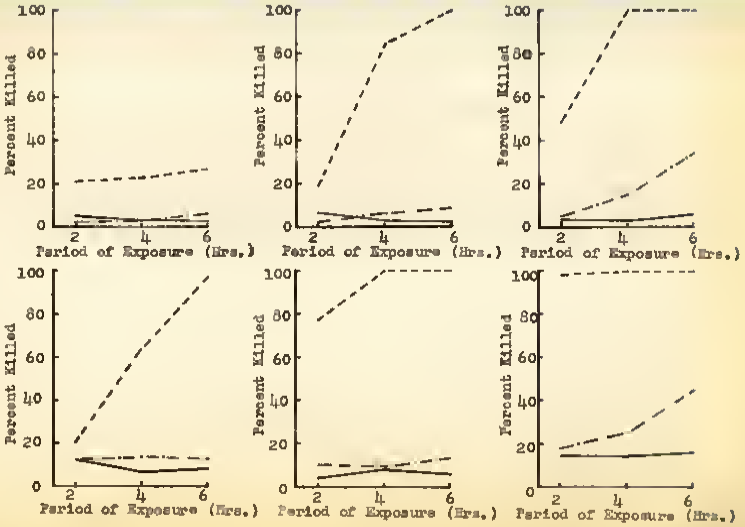
The percentage germination of cucumber seeds soaked in water for 24 hours before treatment as affected by soil fumigant treatments, concentration levels and periods of

Fig. 5.--Effect of period of exposure and concentration of soil fumigants on the germination of damp cucumber seeds. Top, seeds soaked for twelve hours before treatment. Left to right, 0.66 ml., 1.32 ml., and 1.98 ml. per cubic foot of each fumigant. Bottom, seeds soaked for twenty-four hours before treatment. Left to right, 0.66 ml., 1.32 ml., and 1.98 ml. per cubic foot of each fumigant.

———— Check

- - - - D-D

-.-.-.- Dowfume W-40


Percent Killed
100
80
60
40
20
0
2
4
6
Period of Exposure (Hrs.)

exposure are presented in Tables 33, 34, and 35. The results are not discussed in detail since the differences in germination found as a result of soaking for 24 hours prior to exposure are similar to 12 hour soaking, but toxicity of any given concentration is greater after 24 hours of soaking. The percent of damp seeds apparently killed as a result of exposure to soil fumigant treatments at three concentration levels for three periods of time is represented graphically in Fig. 5.

Mustard

The results of germination of mustard seeds soaked in water for 12 hours before treatment as influenced by soil fumigant treatments at different concentration levels and different periods of exposure are presented in Table 36. The data indicate that significant differences were found in the percentage germination between the fumigated and non-fumigated seeds. The fumigant, D-D, was found to be more toxic than Dowfume W-40. The average germination of mustard seeds exposed to fumigants at different concentrations was significantly different for each concentration. Table 37 shows that the period of exposure to the fumigant had a significant influence on the percentage germination of seeds. The seeds exposed to fumigants for four and six hours had a lower germination than seeds exposed for two hours.

TABLE 33

THE PERCENTAGE GERMINATION OF CUCUMBER SEEDS SOAKED FOR 24 HOURS AS INFLUENCED BY EXPOSURE TO SOIL FUMIGANT TREATMENTS, CONCENTRATION LEVELS, AND PERIODS OF TIME

Soil Fumigant Treatment	0.66 ml./s.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Avg.	1.32 ml./s.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Avg.	1.95 ml./s.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Avg.	Average for Soil Fumigant Treatment
Non-Fumigated	87.5	92.5	90.5	90.2	95.5	92.0	94.0	93.8	86.0	85.5	84.0	85.2	89.7
D-D	79.5	35.5	3.0	39.3	23.0	0.0	0.0	7.7	1.8	0.0	0.0	0.6	15.9
DowFume W-40	87.5	85.5	87.0	86.7	90.0	91.0	86.5	89.2	80.5	75.0	55.5	70.3	82.1
Average for Concentration		72.1				63.6				52.0			

L.S.D. for soil fumigant treatment averages at: 5% level = 2.3, 1% level = 3.4

L.S.D. for concentration averages at: 5% level = 1.4, 1% level = 1.8

L.S.D. for individuals (Interaction) at: 5% level = 2.3, 1% level = 3.1

TABLE 34

EFFECT OF CONCENTRATION LEVELS AND THREE PERIODS OF EXPOSURE ON THE PERCENTAGE OF GERMINATION OF CUCUMBER SEEDS SOAKED FOR 24 HOURS

Periods of Exposure (Hours)	Concentration of Fumigant (ml./c.ft.)			Average for Period of Exposure
	0.66	1.32	1.98	
2	84.8	69.5	56.1	70.2
4	71.2	61.0	53.5	61.9
6	60.2	60.2	46.5	55.6

L.S.D. for period of exposure averages at: 5% level = 1.5
1% level = 2.0

L.S.D. for individuals (Interaction) at: 5% level = 2.3
1% level = 3.1

TABLE 35

THE GERMINATION OF CUCUMBER SEEDS SOAKED FOR 24 HOURS AS AFFECTED BY THREE PERIODS OF EXPOSURE TO SOIL FUMIGANTS

Periods of Exposure (Hours)	Soil Fumigant Treatments		
	Non-fumigated	D-D	Dowfume W-40
2	89.7	34.8	86.0
4	90.0	11.8	83.8
6	89.5	1.0	76.3

L.S.D. for individuals (Interaction) at: 5% level = 2.5
1% level = 3.5

The differences found in germination between the seeds exposed for four hours and six hours were also significant. It was found that the periods of exposure interacted with the concentration levels. The exposure of seeds to fumigants at 1.32 and 1.98 ml. per cubic foot for the increasing periods of time resulted in significant decrements of germination. The differences found in germination when damp seeds were exposed to 0.66 ml. per cubic foot for four and six hours were not significant. A significant interaction between the soil fumigant treatments and the three concentration levels was found. This interaction is shown in Table 36. The exposure of seeds to the increasing concentrations of D-D reduced successively the percentage germination of damp mustard seeds. Exposure of seeds to the same concentrations of Dowfume W-40 resulted in lowered germination, but not to the same degree as was found with D-D. A significant interaction between the periods of exposure and soil fumigant treatments was found. This interaction is shown in Table 38. The increasing periods of exposure of seeds to D-D resulted in successive decreases in the percentage germination of seeds. Similar periods of exposure of seeds to Dowfume W-40 reduced the germination, but to a lesser degree than that found with D-D. A significant interaction between soil fumigant treatments, concentration levels, and periods of

TABLE 36

THE PERCENTAGE GERMINATION OF MUSTARD SEEDS SOAKED FOR 12 HOURS AS INFLUENCED BY EXPOSURE TO SOIL FUMIGANT TREATMENTS, CONCENTRATION LEVELS, AND PERIODS OF TIME

Soil Fumigant Treatment	0.66 ml./s.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Ave.	1.32 ml./s.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Ave.	1.98 ml./s.ft. 2 Hrs.	4 Hrs.	6 Hrs.	Ave.	Average for Soil Fumigant Treatment
Non-fumigated	85.5	84.5	87.8	85.9	84.8	88.3	84.5	85.9	83.3	87.3	84.8	85.1	85.6
D-D	79.3	43.5	45.5	56.1	39.0	27.5	0.0	22.2	46.0	12.0	0.0	19.3	32.5
Dowfume W-40	85.3	78.5	79.3	81.0	82.0	73.0	53.0	69.3	81.5	61.0	44.0	62.2	70.8
Average for Concentration		74.4				59.1				55.5			

L.S.D. for soil fumigant treatment averages at: 5% level = 2.0, 1% level = 3.0

L.S.D. for concentration averages at: 5% level = 1.4, 1% level = 1.9

L.S.D. for individuals (Interaction) at: 5% level = 2.4, 1% level = 3.2

TABLE 37

EFFECT OF CONCENTRATION LEVELS AND PERIODS OF EXPOSURE ON THE PERCENTAGE GERMINATION OF MUSTARD SEEDS SOAKED FOR 12 HOURS

Periods of Exposure (Hours)	Concentration of Fumigant (ml./m.ft.)			Average for Period of Exposure
	0.66	1.32	1.98	
2	83.4	68.6	70.3	74.1
4	68.8	62.9	53.4	61.7
6	70.9	45.8	42.9	53.2

L.S.D. for period of exposure averages at: 5% level = 1.8, 1% level = 2.5

L.S.D. for individuals (Interaction) at: 5% level = 2.4, 1% level = 3.2

TABLE 38

THE PERCENTAGE GERMINATION OF MUSTARD SEEDS SOAKED FOR 12 HOURS AS AFFECTED BY THREE PERIODS OF EXPOSURE TO SOIL FUMIGANT TREATMENTS

Periods of Exposure (Hours)	Soil Fumigant Treatments		
	Non-fumigated	D-D	Dowfume W-40
2	84.5	54.8	82.9
4	86.7	27.7	70.8
6	85.7	15.2	58.8

L.S.D. for individuals (Interaction) at: 5% level = 3.2, 1% level = 4.4

exposure was also found. The percent of seeds killed as a result of exposure to fumigants at different concentration levels for three periods of time is represented graphically in Fig. 6.

The effects of soil fumigant treatments, concentration levels and periods of exposure on the germination of mustard seeds soaked in water for 24 hours prior to exposure are presented in Tables 39, 40, and 41. The results obtained with mustard seeds soaked for 24 hours are similar to those soaked for 12 hours, hence they are not discussed in detail. It was noticed that the toxicity of fumigant at any given concentration is greater after 24 hours soaking than after 12 hours soaking. The percent of damp mustard seeds apparently killed by the soil fumigant treatments at different concentration levels and periods of exposure is represented graphically in Fig. 6.

It is apparent from the data presented that the germination of damp seeds was reduced by exposure to D-D and Dowfume W-40, the extent of injury depending upon the type of fumigant, concentration, and length of exposure. The fumigant, D-D, was found to be more toxic to the germination of cucumber and mustard seeds than Dowfume W-40.

The data in Table 42 show the effect of D-D and Dowfume W-40 on the percentage germination of cucumber and mustard seeds soaked in water for 12 and 24 hours before

Fig. 6.--Effect of period of exposure and concentration of soil fumigant on the germination of damp mustard seed. Top, seed soaked for twelve hours before treatment. Left to right: 0.66 ml., 1.32 ml., and 1.98 ml. per cubic foot of each fumigant. Bottom, seed soaked for twenty-four hours before treatment. Left to right: 0.66 ml., 1.32 ml., and 1.98 ml. per cubic foot of each fumigant.

———— Check

- - - - - D-D

—·—·—·— Dowfume W-40

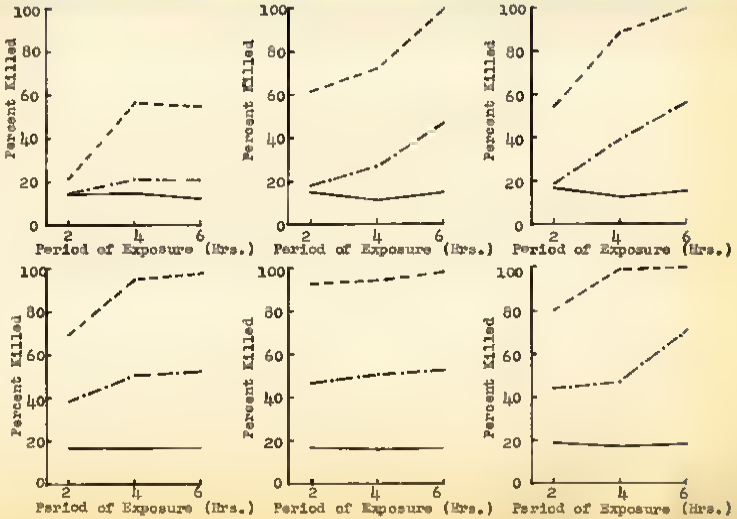

Percent Killed
100
80
60
40
20
0
2
4
6
Period of Exposure (Hrs.)

TABLE 39

THE PERCENTAGE GERMINATION OF MUSTARD SEEDS SOAKED FOR 24 HOURS AS INFLUENCED BY EXPOSURE TO SOIL FUMIGANT TREATMENTS, CONCENTRATION LEVELS, AND PERIODS OF TIME

Soil Fumigant Treatment	0.66 ml./c.ft.				1.32 ml./c.ft.				1.98 ml./c.ft.				Average for Soil Fumigant Treatment
	2 Hrs.	4 Hrs.	6 Hrs.	Avg.	2 Hrs.	4 Hrs.	6 Hrs.	Avg.	2 Hrs.	4 Hrs.	6 Hrs.	Avg.	
Non-fumigated	83.0	83.0	83.0	83.0	83.0	83.5	83.3	83.3	80.3	82.5	81.8	81.5	82.6
D-D	30.5	4.5	2.0	12.3	6.5	5.5	1.3	4.4	19.8	0.8	0.0	6.9	7.9
Dowfume W-40	61.3	48.8	47.8	52.6	52.8	49.0	46.8	49.5	55.3	52.3	28.8	45.5	49.2
Average for Concentration		49.3				45.7				44.6			

L.S.D. for soil fumigant treatment averages at: 5% level = 0.9, 1% level = 1.3

L.S.D. for concentration averages at: 5% level = 1.7, 1% level = 2.3

L.S.D. for individuals (Interaction) at: 5% level = 2.9, 1% level = 3.9

TABLE 40

EFFECT OF CONCENTRATION LEVELS AND THREE PERIODS OF EXPOSURE ON THE PERCENTAGE GERMINATION OF MUSTARD SEEDS SOAKED FOR 24 HOURS

Periods of Exposure (Hours)	Concentration of Fumigant (ml./c.ft.)			Average for Period of Exposure
	0.66	1.32	1.98	
2	58.3	47.4	51.8	52.5
4	45.4	46.0	45.2	45.5
6	44.3	43.8	36.9	41.6

L.S.D. for period of exposure averages at: 5% level = 1.6, 1% level = 2.2

L.S.D. for individuals (Interaction) at: 5% level = 2.9, 1% level = 3.9

TABLE 41

THE GERMINATION OF MUSTARD SEEDS SOAKED FOR 24 HOURS AS AFFECTED BY THREE PERIODS OF EXPOSURE TO SOIL FUMIGANTS

Periods of Exposure (Hours)	Soil Fumigant Treatments		
	Non-fumigated	D-D	Dowfume W-40
2	82.1	18.9	56.5
4	83.0	3.6	50.0
6	82.7	1.1	41.1

L.S.D. for individuals (Interaction) at: 5% level = 2.8, 1% level = 3.8

TABLE 42

THE GERMINATION OF SEEDS SOAKED IN WATER FOR 12 AND 24 HOURS BEFORE TREATMENT AS AFFECTED BY EXPOSURE TO SOIL FUMIGANTS FOR 2 HOURS

Crop Seeds	Concentration ml./c.ft.	D-D			Dowfume W-40		
		Soaked 12 Hrs.	Soaked 24 Hrs.	Shortest Significant Ranges (5% level) 2 Means	Soaked 12 Hrs.	Soaked 24 Hrs.	Shortest Significant Ranges (5% level) 2 Means
Cucumber	0.66	79.0	79.5	2.2	97.5	87.5	6.9
	1.32	81.5	23.0	4.7	98.5	90.0	8.5
	1.98	52.0	1.8	13.1	95.0	80.5	4.3
Mustard	0.66	79.3	30.5	5.4	85.3	61.3	2.6
	1.32	39.0	6.5	4.0	82.0	52.8	3.1
	1.98	46.0	19.8	5.1	81.5	55.3	9.5

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

treatment. The results indicate that significant differences occurred in the percentage germination as a result of exposure to fumigants between the seeds soaked in water for different periods of time. The cucumber seeds soaked in water for 24 hours before treatment and then exposed to D-D and Dowfume W-40 at different concentrations had a significantly lower germination than the seeds soaked for 12 hours. However, no difference was found between the seeds soaked for different periods of time when exposed to D-D at 0.66 ml. per cubic foot. The germination of mustard seeds soaked in water for 24 hours before treatment and exposed to D-D and Dowfume W-40 at the different concentrations was significantly lower than the germination of seeds soaked for 12 hours.

The data in Table 43 show that the cucumber and mustard seeds which were soaked for 12 and 24 hours, fumigated with D-D, and then washed immediately with water did not show any advantage over the non-washed seeds as measured by the changes in the percentage germination. The results obtained on the germination of washed seeds indicate that the influence of fumigant is on the internal parts of the seed.

The analysis of variance for the percentage germination of the two crop seeds tested, when soaked in water for 12 and 24 hours before treatment and exposed to fumi-

TABLE 43

THE GERMINATION OF DAMP SEEDS AS AFFECTED BY EXPOSURE TO D-D AS COMPARED TO THE GERMINATION OF SEEDS WASHED IMMEDIATELY AFTER TREATMENT

Crop Seeds	Periods of Exposure (Hours)	Seed Soaked for 12 Hours				Seed Soaked for 24 Hours			
		0.66 ml.		1.32 ml.		0.66 ml.		1.32 ml.	
		Not Washed	Washed	Not Washed	Washed	Not Washed	Washed	Not Washed	Washed
Cucumber	2	81.0	77.0	80.0	76.0	82.0	79.0	20.5	25.2
	4	76.0	72.0	18.0	15.8	40.0	45.0	0.0	2.0
	6	70.0	67.8	0.0	0.0	0.0	0.0	0.0	0.0
Mustard	2	76.0	72.7	37.2	34.7	28.3	30.6	5.2	4.5
	4	45.0	46.3	25.6	27.2	3.1	1.0	3.7	2.6
	6	42.8	40.0	0.0	1.3	0.0	0.0	0.0	0.0

TABLE 44

ANALYSIS OF VARIANCE FOR THE PERCENTAGE GERMINATION OF CUCUMBER AND MUSTARD SEEDS SOAKED FOR 12 AND 24 HOURS AND EXPOSED TO FUMIGANTS FOR DIFFERENT PERIODS OF TIME

Sources of Variation	D.F.	Sum Squares			
		Cucumber		Mustard	
		12 Hrs.	24 Hrs.	12 Hrs.	24 Hrs.
Grand Total	107	73995.58	86654.13	43580.40	56921.30
Main Treatments	11	42684.99	67784.55	26157.50	51201.69
Soil Fumigants	2	42588.92(xx)	67650.05(xx)	26048.43(xx)	51173.46(xx)
Replications	3	15.57	41.89	35.65	14.43
Error (a)	6	80.50	92.61	72.42	13.80
Exposure Treatments	24	12240.70	6012.40	8588.85	3553.46
Time of Exposure	2	4776.86(xx)	2674.84(xx)	4666.74(xx)	1819.49(xx)
Exposure x Soil Fum.	4	6152.87(xx)	3178.97(xx)	3672.26(xx)	1541.67(xx)
Error (b)	18	308.97	158.59	249.85	192.30

TABLE 44 (Continued)

Sources of Variation	D.F.	Sum Squares			
		Cucumber		Mustard	
		12 Hrs.	24 Hrs.	12 Hrs.	24 Hrs.
Concentration Treatments	72	20069.89	12857.18	8834.05	2166.15
Concentrations	2	7601.17(xx)	5031.48(xx)	3709.05(xx)	309.00(xx)
Conc. x Soil Fum.	4	6758.47(xx)	4347.49(xx)	2889.95(xx)	168.73(x)
Conc. x Time of Exposure	4	2155.56(xx)	446.31(xx)	1162.52(xx)	405.27(xx)
Conc. x Soil Fum. x Exposure	8	2983.85(xx)	2583.74(xx)	597.31(xx)	587.43(xx)
Error (e)	54	570.84	448.16	475.22	695.74

(x) Significant at 5% level
(xx) Significant at 1% level

gants at different concentration levels for different periods of time is presented in Table 44.

Experiment No. 6. Influence of Relative Humidity on the Toxicity of Soil Fumigants

6-A. Effect of Humidity Upon the Toxicity of Soil Fumigants to Seeds

Because of the importance of moisture content of seeds and humidity of the atmosphere on the toxicity of fumigants, a series of fumigation tests were made under controlled conditions of humidity. Table 45 shows the influence on germination of fumigation treatments at 20 and 100 percent relative humidities with D-D to twelve kinds of seeds. The treatment of seeds at 100 percent humidity significantly reduced the germination of seeds as compared to the seeds treated at 20 percent humidity with all but two crop seeds. The germination of these two crops, okra and turnip, was not appreciably affected by D-D either at 20 or 100 percent humidity.

It appears from the data that seeds of some crops are more severely affected than those of others. Although the germination of clover was significantly reduced by exposure to D-D at 100 percent humidity, it still had a comparatively high percentage germination. On the other hand, the germination of lettuce, oats, and rye seeds was very

TABLE 45

EFFECT OF RELATIVE HUMIDITY UPON THE TOXICITY OF D-D TO SEEDS

Crop Seeds	Average Percentage Germination		Shortest Significant Ranges (5% level) 2 Means
	20 Percent Humidity	100 Percent Humidity	
Beets	0.0	0.0	----
Cabbage	73.5	0.0	4.2
Carrots	71.5	0.0	3.8
Clover	64.0	53.5	5.1
Cucumber	71.0	0.0	3.8
Lettuce	70.5	3.5	4.9
Mustard	69.8	0.0	5.9
Oats	68.5	7.5	5.9
Okra	61.5	62.0	5.0
Rye	34.0	6.5	7.1
Spinach	34.0	0.0	3.6
Turnips	61.5	63.8	3.6

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

low and the seeds of the other six crops were apparently killed when treated at 100 percent relative humidity.

The effect of other levels of humidity upon the toxicity of D-D to six selected species of seeds was also determined. Table 46 shows the germination percentages of these seeds when exposed to D-D at various humidities. The data show that there were significant differences in the percentage germination of seeds when treated at different relative humidities. It appears that some crop seeds are more easily injured than other crop seeds when tested under similar conditions. For seeds of mustard and oats a relative humidity of 81 percent was found to result in a significant reduction of germination. On the other hand, the germination of the seeds of cabbage, cucumber, lettuce, and rye was significantly reduced at 51 percent humidity level as compared to seeds treated at 20 percent humidity. From the data presented it is apparent that the toxicity of D-D to the seeds increased as the relative humidity of the atmosphere was increased. The percent of seeds killed by D-D at different levels of humidity is represented graphically in Fig. 7.

The percentage germination of various seeds as influenced by the vapors of Dowfume W-40 at 20 and 100 percent relative humidity is presented in Table 47. The seeds treated at 100 percent relative humidity resulted in a sig-

TABLE 46

EFFECT OF VARIOUS HUMIDITIES UPON THE TOXICITY OF D-D TO SEEDS

Crop Seeds	Average Percentage Germination					Shortest Significant Ranges (5% level)			
	20%	51%	81%	93%	100%	2 Means	3 Means	4 Means	5 Means
Cabbage	73.5	59.0	51.0	44.0	0.0	3.6	3.8	3.9	4.0
Cucumber	71.0	66.5	8.0	6.5	0.0	3.6	3.7	3.9	3.9
Lettuce	78.5	72.8	48.3	40.5	3.5	3.6	3.7	3.9	3.9
Mustard	69.8	69.3	12.3	9.5	0.0	3.3	3.5	3.6	3.6
Oats	62.5	61.0	27.0	27.0	7.5	4.7	4.9	5.0	5.1
Rye	34.0	21.5	13.5	10.5	6.5	3.7	3.8	4.0	4.0

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

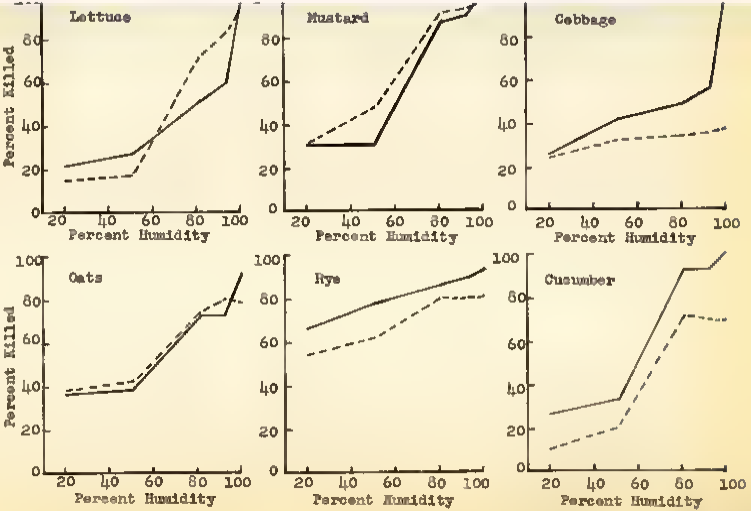


Fig. 7.--Effect of humidity upon the toxicity of soil fumigants to seeds

———— D-D - - - - - Dowfume W-40

TABLE 47

EFFECT OF HUMIDITY UPON THE TOXICITY OF DOWFUME W-40 TO SEEDS

Crop Seeds	Average Percentage Germination		Shortest Significant Ranges (5% level) 2 Means
	20% Humidity	100% Humidity	
Beets	3.5	0.0	4.7
Cabbage	75.5	62.5	5.0
Carrots	73.5	46.3	6.8
Clover	64.8	61.3	5.7
Cucumber	90.0	31.0	10.6
Lettuce	83.8	5.0	6.4
Mustard	69.5	5.0	7.2
Oats	61.0	21.0	6.9
Okra	78.5	75.5	3.9
Rye	45.5	19.0	6.4
Spinach	46.5	0.0	3.2
Turnips	70.5	70.0	4.2

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

nificantly lower germination than that of seeds treated at 20 percent for nine of the twelve crop seeds tested. The germination of three crops--clover, okra, and turnips--was not appreciably affected by treatment at 100 percent humidity. It was again observed that some crop seeds are more severely affected than others. For example, the seeds of cabbage still had a comparatively high level of germination although the germination percentage was significantly reduced when treated at 100 percent humidity. On the other hand the seeds of carrots, cucumber, lettuce, mustard, oats, and rye had a very low level of germination on exposure to fumigant at 100 percent relative humidity. Seeds of beets and spinach were apparently killed, as there was no germination.

The toxicity of Dowfume W-40 on six species of crop seeds at additional levels of humidity was also determined. The germination percentage of seeds as affected by Dowfume W-40 at various levels of humidity is presented in Table 40. Significant differences were found in the germination percentage of seeds treated at low and higher humidities. These tests also indicate that some crop seeds are more susceptible to Dowfume W-40 than the others. Treatment at relative humidity of 81 percent was found to result in a significant lowering of germination of lettuce and oats as compared with the seeds treated at 20 percent humidity,

TABLE 48

EFFECT OF VARIOUS HUMIDITIES UPON THE TOXICITY OF DOWFUME W-40 TO SEEDS

Crop Seeds	Average Percentage Germination					Shortest Significant Ranges (5% level)			
	20%	51%	81%	93%	100%	2	3	4	5
						Means			
Cabbage	75.5	68.0	66.0	64.5	62.5	2.8	2.9	3.1	3.1
Cucumber	90.0	80.0	28.5	30.5	31.0	4.6	4.8	5.0	5.0
Lettuce	83.8	82.0	27.0	16.3	5.0	3.5	3.7	3.8	3.9
Mustard	69.5	52.0	9.0	7.0	5.0	5.3	5.6	5.8	5.8
Oats	61.0	56.5	24.5	20.0	21.0	4.4	4.6	4.8	4.8
Rye	45.5	37.5	19.5	19.5	19.0	4.1	4.3	4.4	4.5

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

whereas the germination of other crop seeds was significantly reduced only when treated at 51 percent humidity. The seeds of cabbage had a comparatively higher percentage germination when treated at all levels of humidity, although the germination was significantly low at higher levels of humidity than at lower humidities. In general, the toxicity of Dowfume W-40 to seeds increased as the relative humidity of the atmosphere was increased. The percent of seeds killed at different levels of humidity is represented graphically in Fig. 7.

It can be concluded from the data presented that the critical humidity level required to cause maximum toxicity of the fumigants depends upon the apparent susceptibility of the seed under examination. It is also evident that the toxicity of the fumigants tested increased with increases in relative humidity of the atmosphere. The fumigant, D-D, was found to be more toxic than Dowfume W-40 at any given humidity.

The tests conducted and the results obtained substantiate the results of others working with relative humidity as a factor in the increased toxicity of other fumigants. Stark (53), working with seeds, Heveadier (35), working with bacteria, and Dobia et al. (12), working with fungi, reported that high humidity during fumigation increased the toxicity of chloropicrin to seeds, bacteria, and fungi respectively.

Experiment No. 6-B. Effect of High Moisture Content of Exposed Seed as Compared to High Humidity in the Atmosphere on the Toxicity of D-D

From the results of the preceding experiment it was evident that the toxicity of fumigant increased with increases in the relative humidity of the atmosphere. Several investigators have explained this phenomenon as due to the seeds absorbing moisture so that the seeds are more susceptible to the vapors of the soil fumigants.

This experiment was designed to find whether the increased toxicity of fumigants in a humid atmosphere was due to a higher moisture content of the seeds or whether it resulted from the presence of a higher relative content of water vapor in the atmosphere itself. Table 49 shows the effects of humidity in the atmosphere upon the toxicity of D-D as exhibited by the germination of cucumber, lettuce, oats, and rye seeds of different moisture contents. Results indicate that significant differences were found in the germination percentage of seeds between fumigation treatments made at 20 and 100 percent relative humidities. The differences in the percentage germinations which were found with seeds held previously at 20 and 100 percent humidities before the fumigation treatment may be due to the actual moisture content of the seeds. These differences were, however, minor when compared to the differences between the relative humidities at which the fumigation treatments were made. If the moisture content of the seeds in the presence of humid atmosphere was the reason for the increased toxicity of the fumigant, those seeds held in the low humidity prior to treatment and then treated at high humidity, should have had the germination affected to the same degree as those seeds held in high humidity prior to treatment and fumigated at low humidity. But such was not the case, indicating that humidity of atmosphere at the time

TABLE 49

ACTION OF RELATIVE HUMIDITY IN THE AIR UPON THE TOXICITY OF D-D TO SEEDS

Crop Seeds	Average Percentage Germination				Shortest Significant Ranges (5% level)		
	Treated at 20% Relative Humidity		Treated at 100% Relative Humidity		2 Means	3 Means	4 Means
	Previously at 20% Humidity	Previously at 100% Humidity	Previously at 20% Humidity	Previously at 100% Humidity			
Cucumber	61.8	29.5	0.0	0.0	4.5	4.7	4.8
Lettuce	94.5	93.5	0.0	0.0	2.9	3.0	3.1
Oats	65.5	34.5	24.0	0.0	3.2	3.4	3.4
Rye	21.0	15.5	8.5	3.0	5.6	5.8	6.0

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

of fumigation was more important than moisture content of seeds for the increased toxicity of D-D.

Stark (53), in a more detailed study on this aspect of the problem, also indicated that high humidity during the time the seeds were exposed to chloropicrin was equally or more important than the moisture content of the seeds.

Experiment No. 7. Effect of Temperature Upon the Toxicity of Soil Fumigants to Seeds

Several investigators have reported increased toxicity of chloropicrin to fungi, bacteria, and seeds with increase in temperature. A test was conducted to see if this was true for seeds exposed to D-D and Dowfume W-40. The apparent toxicity of D-D to seeds as influenced by temperature is presented in Table 50. The data show that significant differences were found in the germination of various seeds at different temperature levels. The treatment with D-D resulted in a decreased germination with increase in temperatures. However, it appears that a rise in temperature over a given range does not exert the same influence on all species of crop seeds. For example, increasing the temperature from 55° to 75°F. markedly increased the toxicity of D-D to cucumber, mustard, oats, and rye at the concentration used, whereas this same change of temperature had less influence on the germination of cabbage and lettuce. The percent of seeds not germinating and apparently killed

TABLE 50

EFFECT OF ROOM TEMPERATURE UPON THE TOXICITY OF D-D TO SEEDS

Crop Seeds	Average Percentage Germination at Temp. of						Shortest Significant Ranges (5% level)				
	55°F.	65°F.	75°F.	85°F.	95°F.	100°F.	2	3	4 Means	5	6
Cabbage	61.0	61.0	58.5	38.5	0.5	5.0	3.9	4.1	4.2	4.3	4.4
Cucumber	69.0	63.0	0.0	0.0	0.0	0.0	1.8	1.9	1.9	2.0	2.0
Lettuce	89.0	70.0	69.8	0.0	0.0	0.5	5.4	5.7	5.9	6.0	6.0
Mustard	71.0	67.0	35.0	16.5	4.3	0.0	2.5	2.7	2.7	2.8	2.8
Oats	65.0	62.0	0.0	0.0	0.0	0.0	2.5	2.7	2.7	2.8	2.8
Rye	25.5	14.5	8.5	6.5	0.5	0.0	4.5	4.7	4.8	4.9	5.0

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

by treatment at different temperatures is represented graphically in Fig. 8.

Table 51 shows the effect of room temperature upon the toxicity of Dowfume W-40 to the germination of seeds. Here again the germination of all crop seeds was reduced by raising the room temperature, seeds of some crops being more severely affected than those of other crops. The seeds of cabbage, cucumber and oats had a relatively high percentage germination at temperatures as high as 85°F. Despite this, the percentage germination at 85°F. was significantly lower than that recorded at 55°F. for cabbage, at 65°F. for oats, and 75°F. for cucumber. Further increase of temperatures with these three crops resulted in significant reduction in germination. The percent of seeds apparently killed by the fumigant at different temperatures is represented graphically in Fig. 8.

It is evident from the data presented that raising the temperature increased the toxicity of both D-D and Dowfume W-40. The critical temperature required to cause maximum toxicity appears to depend upon the susceptibility of the type of seed under examination. Several other investigators working with different fumigants also reported increased toxicity of fumigants with increase in temperature (53, 35, 45).

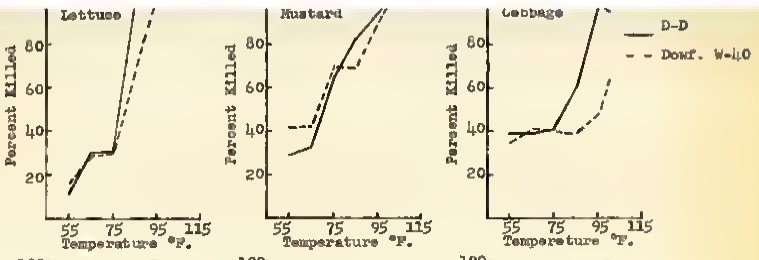


Fig. 8.--Effect of room temperature upon the toxicity of soil fumigants to seeds

TABLE 51

EFFECT OF ROOM TEMPERATURE UPON THE TOXICITY OF DOMFUME W-40 TO SEEDS

Crop Seeds	Average Percentage Germination at Temp. of:						Shortest Significant Ranges (5% level)				
	55°F.	65°F.	75°F.	85°F.	95°F.	100°F.	2	3	4 Means	5	6
Cabbage	64.5	59.0	59.0	61.0	52.0	45.5	4.2	4.4	4.5	4.6	4.6
Cucumber	76.0	74.5	71.0	64.0	20.0	0.0	4.6	4.9	5.0	5.1	5.2
Lettuce	84.0	70.3	69.0	32.0	0.0	0.0	3.3	3.4	3.5	3.6	3.6
Mustard	57.3	57.0	30.3	30.5	9.5	0.3	3.8	4.0	4.1	4.1	4.2
Oats	62.5	63.5	54.0	51.8	26.3	0.0	4.5	4.7	4.9	5.0	5.5
Rye	32.0	25.0	27.0	18.5	6.5	0.5	4.1	4.3	4.4	4.5	4.5

Note: Results not underscored by the same line are significantly different. Results underscored by the same line are not significantly different.

Experiment No. 8. Effect of Soil Fumigants on the Digestion of Starch by Diastase

The transformation of non-available plant food, especially starch, to the available form in the germinating seeds is a well-known phenomenon. It was felt desirable to know whether the soil fumigants would affect this transformation. There was no difference found in the time required for the transformation of starch by diastase between the starch solutions exposed to fumigants and those not exposed.

In general, it was evident that the retarded germination in the case of seeds exposed to soil fumigants under the conditions of the previously described experiments was not due to the non-availability of carbohydrates to the growing embryo. These fumigants might possibly have a toxic effect on other enzymes or on the protoplasm of the seed itself. Townsend (58) also reported that the transformation of starch solution by diastase was not affected by ether.

Experiment No. 9. Effect of Soil Fumigation on Tomato Plants

9-A. Effect of Applying Fumigants in Soil Around Growing Tomato Plants

An experiment was conducted by planting tomato plants in pots to determine the reaction the soil fumigants

produce on growing material. The pots in which one-month old tomato plants were growing were treated by injecting the fumigant into the soil to a depth of 3-4 inches and 2-2 1/2 inches away from the base of the plant. The fumigant was applied at the rate of one milliliter per pot on opposite sides of the plant. Plate II shows three tomato plants under the three different soil treatments. The use of D-D and Dowfume W-40 produced the same symptoms and finally killed the plants. Within a day or two after fumigation the plants showed symptoms of wilting, especially in the actively growing regions of the plant, followed by yellowing of the older leaves. The entire plant turned yellow in 5 to 6 days after fumigation with both the fumigants. In the case of Dowfume W-40, the stem of the plant became soft and bent down, due to the heavy weight of the top, while in the case of D-D, the stem stood erect until the plant died. The plants treated with Dowfume W-40 were killed much faster than those treated with D-D. The plants in non-treated soil grew normally.

An examination of transverse sections of stem under the microscope showed a browning of vascular bundles. This browning was visible even to the naked eye when freshly cut stems of the treated plants were observed. Examination of the root system indicated browning and final death of roots in both cases, whereas the non-treated plants were normal.

Effect of Soil Treatment on One Month Old Tomato Plants
Left to Right, Check, Dowfume W-40, and D-D

Experiment No. 9-B. Effect of Time of Application of Soil Fumigants on Transplanted Tomato Seedlings

The percentage survival of transplanted tomato seedlings as influenced by time of previous soil fumigation is presented in Table 52. Statistical analysis shows that the percentage survival of transplanted tomato seedlings in the soil treated previously with D-D and Dowfume W-40 was significantly lower than in unfumigated soil. In comparing the results on the use of D-D with Dowfume W-40, the difference was highly significant. The data show that the time of transplanting after fumigation had a highly significant influence on the stand of the plants. The percentage survival of plants transplanted 5 and 10 days after fumigation was significantly higher than when planted on the same day as fumigation. The number of seedlings surviving when transplanted 10 days after fumigation was significantly higher than when planted 5 days after fumigation. A significant interaction was found between time of application of fumigant before planting and soil fumigation treatment.

It is interesting to note that the treatment with Dowfume W-40 was found to be more toxic than D-D to transplanted seedlings planted five days after soil treatment. There was no difference found in the percentage survival

TABLE 52

EFFECT OF TIME OF SOIL FUMIGATION ON PERCENTAGE SURVIVAL OF TRANSPLANTED TOMATO SEEDLINGS

Soil Fumigation Treatment	Time of Application Before Planting (Days)			Average for Soil Fumigation Treatment
	0	5	10	
Check	94.5	94.3	97.5	95.4
D-D	1.5	80.0	94.5	58.7
Dowfume W-40	3.5	38.5	96.5	46.2
Average for time of Application	33.2	70.9	96.2	

L.S.D. for soil fumigation treatment averages and time of application averages at: 5% level = 3.8, 1% level = 5.2

L.S.D. for individuals (Interaction) at: 5% level = 6.6, 1% level = 9.0

of plants between the two soil fumigants when planted on the same day and ten days after soil fumigation.

Field observations showed yellowing of the leaves and final death of most plants when the tomato seedlings were planted on the day of fumigation. Death of many seedlings was observed in the case of those planted five days after fumigation. The appearance of the plants was that which was described in the pot culture experiment. However, there was no visible difference in the growth of the plants

transplanted ten days after fumigation and of those in the non-treated soil.

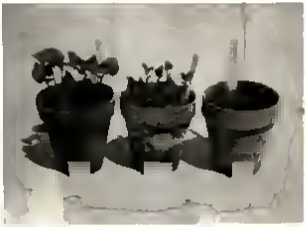
Favris (46) studied the effect of D-D and trichlorobutenes at the rate of 190 and 380 pounds per acre, respectively, on transplanted tomato seedlings. He found injury to seedlings when transplanted 14 days after fumigation. This, he explained as due to the soil being low in organic matter and poorly drained. Nettles (43) indicated that 2-3 weeks time should elapse before planting when D-D and ethylene dibromide are applied to soil.

Experiment No. 10. Effect of Soil Fumigants on Germination of Bean Seeds

10-A. Effect of Soil Fumigation Immediately after Planting Bean Seeds

A test was made in pots to determine the effect of soil fumigants on the germination of bean seeds. Ten seeds were planted in each pot and the soil was then treated by injecting one milliliter of fumigant in the center of the pot to a depth of 2-3 inches. Plate III shows the germination of bean seeds ten days after planting under three different soil treatments. The germination of seeds planted in D-D fumigated soil was lower than those planted in unfumigated soil and in soil treated with Dowfume W-40. Only three out of ten seeds planted ger-

PLATE III



Effect of Soil Fumigant Treatments on the Germination of Bean Seeds
Left to Right, Check, Dowfume W-40, and D-D

minated in the soil treated with D-D and the seedlings were stunted in growth. The number of seeds germinated in the soil treated with Dowfume W-40 was equal to those germinated in the non-treated soil, but the seedlings were intermediate in size between those in the D-D treatment and in untreated soil.

Delay in germination was another effect noted due to the treatments. The germination of seeds was delayed by 4 to 5 days by treatment with D-D and by 2 to 3 days by treatment with Dowfume W-40.

Experiment No. 10-B. Effect of Time of Previous Application of Soil Fumigants on Field Germination of Bean Seeds

Numerous investigators have reported the susceptibility of bean seedlings to soil fumigants even when sown several months after fumigation, and therefore the germination of bean seeds in soils treated previously with D-D and Dowfume W-40 was studied. The effect of soil fumigant treatments at three intervals on the germination of bean seeds is presented in Table 53. The number of seeds germinating in the fumigated plots was significantly less than the number of seeds germinating in the non-fumigated plots for all time intervals used. The treatment of soil with D-D significantly reduced the germination of bean seeds more than did the treatment with Dowfume W-40. The

TABLE 53

EFFECT OF TIME OF APPLICATION OF SOIL FUMIGANTS ON THE PERCENTAGE GERMINATION OF BEAN SEEDS

Soil Fumigation Treatment	Time of Application Before Seeding (Days)			Average for Soil Fumigation Treatment
	0	5	10	
Check	90.8	89.8	88.8	89.8
D-D	77.0	79.5	79.5	78.7
Dowfume W-40	82.5	83.5	83.5	83.2
Average for time of Application	83.4	84.3	83.9	
L.S.D. for soil fumigation treatment averages and time of application averages at:			5% level = 3.2 1% level = 4.4	
L.S.D. for individuals (Interaction) at:			5% level = 5.6 1% level = 7.6	

time interval between fumigation and seeding did not show any significant influence on the germination of the bean seeds under these conditions of soil treatment at the rate of 3-4 ml. per cubic foot. The "F" test for interaction between fumigation treatments and time of application showed no significance. The seeds planted the same day of fumigation germinated as well as those planted 5 days and 10 days after fumigation, although delay in germination was noticed in the plots treated with D-D.

Farris (46) found no toxic effect of D-D on peas planted 24 and 72 hours after treatment when he applied the fumigant at the rate of 150 pounds per acre. However, he noticed injury to beans planted 18 days after fumigation. Taylor (56) reported no injury to cucumber seeds with methyl bromide when he planted soon after fumigation of soil at the rate of 5.6 pounds per 1,000 cubic feet at 27°F. for 72 hours. Clayton and Ellis (7) reported low yields of beans when planted seven months after soil treatment with D-D. Nettles (42) recorded increased yields of beans in all plots treated with D-D and Dowfume W-40 two weeks prior to planting.

Experiment No. 11. Effect of Soil Fumigants at Different Soil Temperatures on the Germination of Seeds

The seeds in this test were planted one hour before soil treatment. The data presented in Table 54 show that the germination of bean seeds was significantly lower when planted in fumigated than in non-fumigated soils, and in soil treated with D-D than in soil treated with Dowfume W-40. Differences in the germination of bean seeds were also

TABLE 54

EFFECT OF SOIL FUMIGANTS ON THE PERCENTAGE GERMINATION OF BEAN SEEDS PLANTED AT DIFFERENT SOIL TEMPERATURES

Soil Fumigation Treatment	Soil Temperatures					Average for Soil Fumigation Treatment
	55°F.	68°F.	75°F.	86°F.	92°F.	
Check	85.0	82.5	82.3	82.5	81.5	82.8
D-D	34.5	21.0	27.0	25.3	61.5	33.9
Dowfume W-40	49.0	39.0	44.5	46.5	63.8	48.6
Average for Soil Temperature	56.2	47.5	51.3	51.4	68.9	

L.S.D. for soil fumigation treatment averages at: 5% level = 1.6, 1% level = 2.1

L.S.D. for soil temperature averages at: 5% level = 2.1, 1% level = 2.8

L.S.D. for individuals (Interaction) at: 5% level = 3.6, 1% level = 4.8

found when planted in soils at different temperatures. It appears from the data that as the soil temperature was increased above 68°F, there was a gradual decrease in toxicity of fumigants to bean seeds. It is noted also that at 92°F, the germination of beans planted in soil treated with D-D equalled the germination of beans planted in soil treated with Dowfume W-40, although at lower temperatures the D-D treatment was found to be more toxic than the Dowfume W-40

treatment. The critical soil temperature for the maximum toxicity of the soil fumigant to bean seeds appears to be in the vicinity of 68°F. The germination percentage of bean seeds planted in soil treated at different temperatures is represented graphically in Fig. 9.

Table 55 shows the effect of soil fumigants on the germination percentage of watermelon seeds planted in soils at different temperatures. Results indicate that highly significant differences occurred in the germination of watermelon seeds planted in fumigated and non-fumigated soils. Also, D-D significantly reduced germination more than Dowfume W-40. Significant differences were found between the germination percentages of watermelon seeds planted in soils at different temperatures. The data indicate that as the soil temperature is increased above 68°F. there was a significant increase in germination. The critical temperature for maximum toxicity was found to be in the vicinity of 68°F. for the soil as indicated in this test. The germination percentage of watermelon seeds planted in treated soil at different temperatures is represented graphically in Fig. 9.

It is evident that raising the soil temperature from 55° to 68°F. increased the toxicity of fumigants slightly, but raising the temperature of soil over 68°F. decreased the toxicity of fumigants on the germination

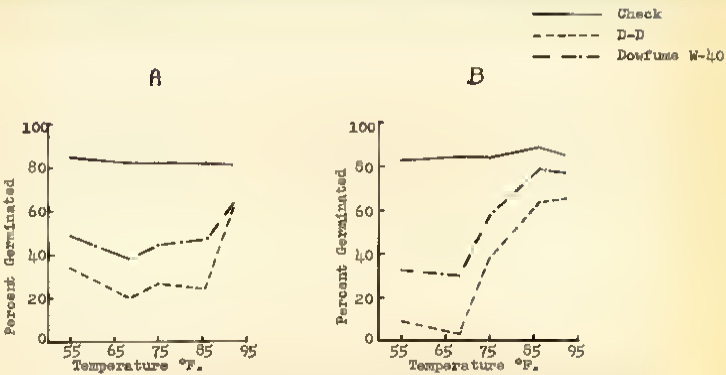


Fig. 9.--Percentage germination of A-bean seeds and B-watermelon seeds planted in fumigated soil at different soil temperatures.

TABLE 55

EFFECT OF SOIL FUMIGANTS ON THE PERCENTAGE GERMINATION OF WATERMELON SEEDS AT DIFFERENT SOIL TEMPERATURES

Soil Fumigation Treatment	Soil Temperatures					Average for Soil Fumigation Treatment
	55°F.	68°F.	75°F.	86°F.	92°F.	
Check	82.5	84.5	84.0	89.5	85.5	85.2
D-D	9.0	2.8	38.0	63.0	65.5	35.7
Dowfume W-40	32.5	30.0	58.0	78.0	77.0	55.1
Average for Soil Temperatures	41.3	39.1	60.0	76.8	74.0	

L.S.D. for soil fumigation treatment averages at: 5% level = 1.9, 1% level = 2.6

L.S.D. for soil temperature averages at: 5% level = 2.5, 1% level = 3.4

L.S.D. for individuals (Interaction) at: 5% level = 4.4, 1% level = 5.9

of watermelon and bean seeds. This decreased toxicity may result from quick drying of the surface soil due to the shallowness of soil in the metal pans and escape of the vapors of the soil fumigants from the soil before any lethal doses were accumulated in the seed. The higher toxicity of each of the soil fumigants at lower temperatures could be due to the retention of fumigants in the soil for a longer time resulting from lowering of the volatility and diffusion of vapors.

The above-mentioned observations substantiate the results obtained with ethylene dibromide by Turner and Dister (59). They indicated that best results with ethylene dibromide could be obtained if the soil temperature was in the medium range at a depth of 6-8 inches. On the other hand, if soil temperature was too high, the fumigant might diffuse too rapidly and escape from the soil before lethal concentrations were maintained for sufficient time to kill the pathogenic organisms. This is especially true if soil moisture is low. Low soil temperatures will interfere with aeration of soil and retard the diffusion of the vapors of fumigants which might remain as toxic residues for a longer time.

Experiment No. 12. Effect of Quantity and Time of Application of Water Seal to the Soil Surface on the Toxicity of Soil Fumigants to the Germination Quality of Sweet Corn

The effect of soil fumigation with D-D and water seal treatments on the percentage germination of sweet corn is shown in Table 56. The data show significant differences between the soil textures, sandy and sandy loam, when treated with D-D. The interaction between soil textures used and the water seal treatments was found to be statistically significant. In sandy soil, D-D treatment was less toxic than in soils with sandy

TABLE 56

EFFECT OF QUANTITY AND TIME OF APPLICATION OF WATER SEAL UPON THE TOXICITY OF D-D TREATMENT AS MEASURED BY THE GERMINATION OF CORN SEEDS PLANTED IN SOIL 4 HOURS BEFORE TREATMENT

Texture of Soil	Water Seal Treatments					Average for Texture of Soil
	Check	No Water Seal	100 ml. Water 2 Hrs. after Fumigation	100 ml. Water Immediately After Fumigation	200 ml. Water Immediately After Fumigation	
Sandy	93.0%	85.3%	82.3%	72.3%	59.3%	78.4
Sandy Loam	94.0	82.0	64.8	60.8	1.5	60.6
Average for Water Seal Treatments	93.5	83.7	73.6	66.6	30.4	

L.S.D. for water seal treatment averages at: 5% level = 3.1, 1% level = 4.2

L.S.D. for soil texture averages at: 5% level = 2.0, 1% level = 2.7

L.S.D. for individuals (Interaction) at: 5% level = 4.4, 1% level = 5.9

loam texture. This may be due to the more rapid drying of the surface permitting the escape of the vapors of the soil fumigant. The effect of the use of a water seal on the toxicity of D-D to the germination of sweet corn is striking. The differences found between the several water-seal treatments were highly significant. The amount of water applied made a pronounced difference on the toxicity of D-D. When 100 ml. of water was applied immediately after fumigation as a water seal, 72.3 and 60.8 percent of sweet corn germinated in soils of sandy and sandy-loam texture respectively. But when 200 ml. of water was applied immediately after soil fumigation, 59.3 and 1.5 percent germinated in soils of sandy and sandy-loam texture respectively. The higher percentage germination when 100 ml. of water was applied may be due to the more rapid evaporation of this small amount of water, permitting the escape of the vapors of D-D. The two-hour time interval between the fumigation and the application of the water seal appeared to have significant influence on the toxicity of D-D to sweet corn seeds. The applying of 100 ml. of water immediately after fumigation significantly reduced the germination of sweet corn as compared to waiting two hours after fumigation to apply the water, and this effect is more pronounced in a sandy soil than in a sandy loam.

Table 57 shows the effect of the quantity and the time of application of a water seal to the surface soil on the efficacy of Dowfume W-40 in soils of two textures. Highly significant differences in the percentage germination of sweet corn seeds were found to result between the two textures of soils tested, as Dowfume W-40 was found to be less toxic in sandy soil than in soils of sandy loam texture. The data show that highly significant differences also occurred between the different water-sealing treatments. The interaction between the two soil textures and the five water-sealing treatments was highly significant. The amount of water used for sealing the soil surface had a significant influence on the toxicity of Dowfume W-40 as measured by the germination of sweet corn. Germination was significantly reduced when 200 ml. of water was used as compared to 100 ml. The time interval of two hours between fumigation and the application of the water seal also had a marked influence on the toxicity of Dowfume W-40. Germination of sweet corn was significantly reduced when 100 ml. of water was applied as a surface seal immediately after fumigation as compared to its application two hours after fumigation. This reduction was greater in sandy soil than in sandy-loam soil.

Stark (53), working with chloropicrin, reported that a water seal should be applied as soon as possible

TABLE 57

EFFECT OF QUANTITY AND TIME OF APPLICATION OF WATER SEAL UPON THE TOXICITY OF DOWFUME W-40 TREATMENT AS MEASURED BY THE GERMINATION OF CORN SEEDS PLANTED IN SOIL 4 HOURS BEFORE TREATMENT

Texture of Soil	Water Seal Treatments					Average for Texture of Soil
	Check	No Water Seal	100 ml. Water 2 Hrs. After Fumigation	100 ml. Water Immediately After Fumigation	200 ml. Water Immediately After Fumigation	
Sandy	93.0%	87.5%	81.3%	73.5%	59.5%	78.9
Sandy Loam	92.5	84.8	65.8	62.0	17.0	64.4
Average for Water Seal Treatments	92.8	86.2	73.6	67.8	38.3	

L.S.D. for water seal treatment averages at: 5% level = 3.8, 1% level = 5.2

L.S.D. for soil texture averages at: 5% level = 2.4, 1% level = 3.3

L.S.D. for individuals (Interaction) at: 5% level = 5.4, 1% level = 7.3

after fumigation was done. He also indicated that the amount of water applied made little difference so long as the entire surface was wet. It is most important that a water seal should be applied to all warm, porous soils. Wetting of the soil to a depth of one inch or less was adequate. Overwatering immediately after treatment might be detrimental.

SUMMARY AND CONCLUSIONS

The germination of seeds was partially inhibited in the presence of the vapors of the soil fumigants, D-D and Dowfume W-40, and the relative susceptibility of the seeds was found to vary with the type of the seed and the fumigant used. The vapors of D-D were more toxic to the germinating ability of most seeds than those of Dowfume W-40.

The length of exposure of seeds to fumigants had a marked influence on the germination. Seeds exposed to fumigants for 4 to 5 days and then removed from the presence of the fumigants had higher percentage of germination than similar seeds germinated while being continuously exposed to the fumigants.

Water which was exposed to the higher concentration of fumigants absorbed sufficient amounts to markedly inhibit the germination of seeds when used to water them. The extent of influence of the exposed water on cucumber seeds depended upon the length of exposure and the concentration of the fumigant, with D-D being more toxic than Dowfume W-40. Higher counts of abnormal seedlings were also made with cucumber seeds which were moistened with water exposed to D-D than to Dowfume W-40. An aeration

period of two weeks reduced the toxicity of the water, particularly at the lower concentration and short periods of exposure to D-D.

The pH of water was found to be lowered by exposure to these fumigants. The change of pH was directly proportional to the concentration of fumigant and length of exposure, and was more pronounced when 50 ml. of water was exposed than 100 ml. of water. D-D had a more marked influence on pH changes than Dowfume W-40. The pH of water exposed to fumigants was not affected by subsequent aeration of one and two weeks' duration.

The germination capacity of various seeds was not affected by water at a pH of 3.1 which was comparable to that produced by exposure of water to the soil fumigants.

The exposure of dry cucumber seeds to the vapors of the soil fumigants had a marked effect on the subsequent germination, with D-D being more toxic than Dowfume W-40. As indicated in other experiments, the influence of the fumigant depended upon the concentration of fumigant and length of exposure. An aeration period of ten days after exposure and prior to germination increased the percentage germination.

Cucumber and mustard seeds soaked in water for 12 and 24 hours prior to exposure to the vapors of fumigants had lowered germination. Those soaked in water for 24 hours

were more injured by the vapors of D-D and Dowfume W-40 than seeds soaked for 12 hours. The extent of influence of the fumigants on damp seeds depended upon the concentration of fumigant and length of exposure. D-D had a more toxic effect than Dowfume W-40, and tests indicated that the inhernal parts of the seed are affected by D-D.

With increase in the relative humidity of the atmosphere in closed chambers, the toxicity of fumigants to seed becomes greater. The critical humidity for the maximum damage to the seed was influenced by the inherent susceptibility of the type of seed being tested. With D-D, tests showed that the relative humidity in the chambers during the time of fumigation was more important than the moisture content of the seed.

The toxicity of fumigants to seeds was greater as temperature increased. The critical temperature for the maximum damage to seeds varied with the type of seed tested, but was generally in the vicinity of 68°F.

The transformation of starch by diastase was not influenced by the fumigants, D-D and Dowfume W-40. It is considered that the retardation of the germination capacity of seeds was not due to the non-availability of carbohydrates but might probably be due to the direct influence of fumigants on the protoplasm of seed or on oxidation-reduction systems.

Treating soils in which tomato plants were growing with fumigants resulted in yellowing of the leaves and in final death of plants. Treatment with Dowfume W-40 killed the plants faster than that with D-D. An examination of transverse sections of stems showed browning of the vascular bundles. Examination of root system also showed browning and final death of roots.

Tomato plants transplanted on the same day of soil treatment with D-D and Dowfume W-40 were killed. When planted five days after soil fumigation, 62 percent of the seedlings were killed by Dowfume W-40. Fumigation with D-D did not affect the stand of the plants as much as treatment with Dowfume W-40. Seedlings transplanted ten days after soil fumigation grew normally.

The germination of bean seeds was depressed in soil treated with D-D, and the seedlings were stunted in growth. Seedlings produced following fumigation with Dowfume W-40 were intermediate in size between the check and D-D treatment. Delay in germination of seeds was caused by both fumigation treatments.

Soil fumigation with D-D and Dowfume W-40 prior to planting reduced the percentage germination of bean seeds, and D-D reduced the germination more than Dowfume W-40. The time interval after soil treatment before seeding did not show appreciable influence on the percentage germination.

Treatments with D-D and Dowfume W-40 at different soil temperatures markedly affected the germination of bean and watermelon seeds. D-D was found to reduce germination of these seeds more than Dowfume W-40 at all temperatures. It was found that the toxicity of these fumigants to the seeds was reduced at higher soil temperatures.

A water seal immediately after soil fumigation increased the repressing effect of the fumigants on germination of sweet corn seeds. The greater the amount of water used to wet the soil surface, the more toxic the fumigant was found to be. The fumigants, D-D and Dowfume W-40, had less influence on the germination of corn seeds in soils having sandy texture than in soils having sandy loam texture.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of the committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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